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THESIS

INTEGRATING THE DEPARTMENT OF DEFENSE MILITARY SERVICES' TECHNOLOGY DEVELOPMENT PROGRAMS TO IMPROVE TIME, COST, AND TECHNICAL QUALITY PARAMETERS

by

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March 2007

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13. ABSTRACT

Currently, the Air Force is developing the Space Radar (SR) system, the Navy the DD(X) 21st Century Destroyer, and the Army the Future Combat Systems (FCS). While technologies developed by the Research, Development, Test, and Evaluation (RDT&E) organizations affiliated with each military service often have pervasive utility among the services, the structures of these RDT&E organizations currently do not provide for or permit any substantial degree of synergistic teaming, integration, or technology leveraging. As a result, technology development for each of the SR, DD(X), and FCS programs has failed to achieve schedule efficiency, cost effectiveness, and technical proficiency. To enable a successful development of these systems in particular and to prevent DoD system acquisition programs from failing to achieve the aforementioned parameters, a leveraged technology development strategy is needed.

This thesis examined the potential for inter-service technology development and identified opportunities to leverage the development of common, critical technologies across the three services within the DoD in general and across the SR, DD(X), and FCS programs in particular.

The findings of this study show that through careful planning and coordinated technology transition, DoD acquisition programs can indeed leverage the technology development efforts of the three services within the DoD. The identified technology leveraging opportunities will enable significant cost savings and schedule efficiency to the Space Radar, DD(X), and Future Combat Systems programs and help ensure deployment of these critical defense capabilities.

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INTEGRATING THE DEPARTMENT OF DEFENSE MILITARY SERVICES' TECHNOLOGY DEVELOPMENT PROGRAMS TO IMPROVE TIME, COST, AND TECHNICAL QUALITY PARAMETERS

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Currently, the Air Force is developing the Space Radar (SR) system, the Navy the DD(X) 21st century Destroyer, and the Army the Future Combat Systems (FCS). While technologies developed by the Research, Development, Test, and Evaluation (RDT&E) organizations affiliated with each military service often have pervasive utility among the services, the structures of these RDT&E organizations currently do not provide for or permit any substantial degree of synergistic teaming, integration, or technology leveraging. As a result, technology development for each of the SR, DD(X), and FCS programs has failed to achieve schedule efficiency, cost effectiveness, and technical proficiency. To enable a successful development of these systems in particular and to prevent DoD system acquisition programs from failing to achieve the aforementioned parameters, a leveraged technology development strategy is needed.

This thesis examined the potential for inter-service technology development and identified opportunities to leverage the development of common, critical technologies across the three services within the DoD in general and across the SR, DD(X), and FCS programs in particular.

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Thank you for supporting me through everything. I could not have accomplished this master's degree without you by side. I will love you always.

To My Son Barry Jr:

Thank you for coming into my life and giving me focus. You help me see clearly every day and you make me strive to be a better father, husband, and individual. I love you with everything I have.

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EXECUTIVE SUMMARY

Currently, the Air Force is developing the Space Radar (SR) system, the Navy the DD(X) 21st century Destroyer, and the Army the Future Combat Systems (FCS). While technologies developed by the Research, Development, Test, and Evaluation (RDT&E) organizations affiliated with each military service often have pervasive utility among the services, yet the structures of these RDT&E organizations currently do not provide for or permit any substantial degree of synergistic teaming, integration, or technology leveraging. As a result, technology development for each of the SR, DD(X), and FCS programs has failed to achieve schedule efficiency, cost effectiveness, and technical proficiency. Such failure is not unique to these system development programs. DoD system acquisition programs have been plagued with spiraling cost overruns and schedule slips, which can be attributed to inadequate technology development and transition processes, a weakened U.S. industrial base, and a reduction in funding for the DoD research laboratories. To enable a successful development of these systems in particular and to prevent DoD system acquisition programs from such plague in general, a technology development leveraging strategy is needed that effectively offsets those attributing problems.

The purpose of this thesis consists of examining the potential for inter-service technology development and identifying opportunities to leverage the development of common, critical technologies across the three services within the DoD in general and across the SR, DD(X), and FCS programs in particular.

This study utilizes a methodical strategy to identify the development leveraging opportunities. The Technical Requirements Documents (TRD), congressional budget information, and other key documents for the SR, DD(X), and FCS programs are reviewed in order to identify the technologies critical to those programs, from which the common technologies amongst the three programs are then identified. An assessment of DoD development capability is conducted to determine the level of specialization and competency attained by

the Science and Technology (S&T) Labs of the three services. The demonstrated development experience of each of the S&T Labs is then compared with the system development requirements to determine which of the service labs is best suited to develop the common critical technologies and integrate the matured products across the three programs.

The findings of this research follow. First of all, the SR program needs to integrate key technologies such as Ground Moving Target Indication (GMTI) Hardware and Software and Lithium Ion batteries before the SR system can be deemed operational; the DD(X) program needs significant advancements in Electronically Scanned Array (ESA) radar technology as well as design improvements in energy storage and on-ship computing technologies; and the FCS program requires new technologies in materials, ordinance, and radar systems.

Second, Lithium Ion Batteries and Electronically Scanned Arrays are two common technologies required by the three systems, thus representing opportunities for technology development leveraging. The Army Research Lab has the development expertise and demonstrated manufacturing experience necessary to develop the Lithium Ion Battery technology for all three DoD programs. The ARL development of this technology will also provide benefits to the industrial base through the ARL strategic partnerships with industrial battery manufacturers. The Naval Research Lab has the design, integration, and application experience necessary to develop the Electronically Scanned Array technology for the SR, DD(X), and FCS programs.

Finally, through careful planning and coordinated technology transition, DoD acquisition programs can indeed leverage the technology development efforts of the three services within the DoD. The technology leveraging will enable significant cost savings and schedule efficiency to these acquisition programs and help ensure deployment of these critical defense capabilities.

I. INTRODUCTION

A. BACKGROUND

In the 21st century, military conflicts such as the Persian Gulf War and Operation Enduring Freedom *(Curtin, 2004)* are waged through utilization of un-manned aerial drones, Global Positioning System (GPS) guided bombs, infrared satellite imagery, laser-guided munitions, and weapons of high precision and lethality could only be imagined 100 years ago. In addition to advanced tactical weapons, current communication and military satellites, such as the MILSTAR and Space Based Infra-Red systems (*Elfers, 2002*), have endowed defense forces with an unprecedented level of mission-specific, time critical data that has revolutionized the way conflict is approached, strategies developed, and wars executed.

State-of-the-art technologies represent the enabling component of this 21st century military doctrine and are the cornerstones of every fielded Department of Defense (DoD) acquisition program (*Michael Sullivan, 2005*). These technologies provide new functionality and capabilities to the weapons that the U.S. military uses *(Sgt. Shane A. Cuomo, 2006)*. Furthermore, every DoD acquisition program, *past and present*, relies on technology in order to develop a functional system that can meet specific operational requirements. Prior to the system being deployed and before any hardware can be manufactured, the technology enabling the system operation must have progressed from a state of basic scientific research to a full demonstration of capability in a relevant environment *(Missile Defense Agency, 2005)*. Once demonstrated in a relevant environment, but before any system manufacturing processes can begin, this technology must be designed and integrated into a producible, end-item component that is further demonstrated for operational readiness *(Missile Defense Agency, 2005)*. This arduous process of developing and integrating

technology into a useable end-item can be broken into two distinct components: Technology Development and Technology Transition *(Meeks, 2003)*.

Technology development is defined by the National Science Foundation (NSF) as the " . . . activities comprising creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" *(Meeks, 2003).* Additionally, this development is ". . . directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements." (*DoD Financial Management Regulation, 2004*) Technology development is thus the process used to increase the general knowledge level of a particular science, and the follow-on application of that knowledge to design, build, or improve systems or processes to meet specific user requirements. Within the DoD, this type of development work is normally performed at a government laboratory or, more specifically, by a Research, Development, Test, and Evaluation (RDT&E) organization. These government organizations, unique to each military service, are charged with developing and maintaining strategic roadmaps, coordinating technology investments across the DoD, and with the general oversight and stewardship of technology maturation for those technologies identified to have use and applicability to their respective branch of service.

Technology Transition is defined as the ". . . process by which technology deemed to be of significant use to the operational military community is transitioned from the science and technology environment to a military operational field unit for evaluation and then incorporated into an existing acquisition program or identified as the subject matter for a new acquisition program." *(Dobbins, 2005)* The objective of technology transition is to ensure that individual technologies are integrated into a full operational system in an efficient and expeditious manner, while maintaining overall quality and affordability metrics. Although key to developing and fielding an operationally

effective system, technology transition is often overlooked and, mistakenly, uncoordinated with technology development efforts. Concerns regarding the program's funding and rigid schedule constraints tend to promote this mistake. The Government Accounting Office (GAO) recently stated that technology development uncoordinated with technology transition ". . . invariably leads to unanticipated cost and schedule increases for space and other weapon system programs since technical problems occurring within acquisition require more time and money to fix. For some large programs for space, cost increases have amounted to billions of dollars and delayed schedules by years. Aside from removing technology [transition] from a more protective environment and from Science & Technology oversight processes, problematic acquisitions may also rob the S&T community and other acquisition programs of investment dollars." *(Sullivan, 2005)* As evidenced by the GAO's findings, it is imperative that technology transition be carefully linked and coordinated with a sound transition strategy in order to ensure successful system acquisition and to minimize the occurrence of these cost and schedule issues.

Additionally, many of the DoD's acquisitions programs face great difficulty in developing their necessary technologies due to myriad issues related to the U.S.'s weakened industrial base for technology components *(Davis, 2006)*. In a recent Aerospace Corporation study [Mayer, 2004] identifies some of the industrial base issues faced by U.S. defense industry. Simple economic issues, such as low volume and industry consolidation, hinder the ability of U.S. companies to compete on the open market, while the other issues, such as minimal Government S&T dollars and an insufficient engineering skill base, limit the ability of the industrial base to grow and thrive. Self-inflicted government policies, such as our stringent environmental safety regulations and the U.S International Traffic in Arms Regulation (ITARs), place further limitations on the U.S. industrial base.

Common “Root Causes” of IB Issues

- Low Volume / Low Margin
  - Product volume or profit margin is insufficient to sustain robust industrial base
- Foreign Trade Restrictions
  - Restrictions inhibit development of domestic commercial sources for military applications, prevent optimization of foreign products
- Foreign Competition
  - Viability of domestic suppliers is threatened by foreign competition
- No Domestic Materials Source
  - Domestic industry is dependent on foreign source of materials
- Industry Consolidation / Contractor Availability & Capacity
  - Structure of domestic corporations inhibits support of small manufacturing base
- People / Demographics / Critical Skills
  - Available engineering skills base is insufficient to sustain robust industrial base
- Technical or Technological
  - Domestic industry cannot provide products with sufficient capability
- Industry & Government Investment
  - Research investment is not sufficient to support continuing industrial base
- Environmental / Safety Regulations
  - Regulations add cost and infrastructure to domestic industrial base
- Other Government Policies, Processes, Culture
  - US or foreign govt. policies may reduce competitiveness of domestic industrial base
- Infrastructure: Facilities, Equipment, Information Technology, Security
  - Domestic infrastructure cannot support robust industrial base

Figure 1.1: Aerospace Corporation Industrial Base (IB) Study
(From: Mayer, 2004)

The issues described in Figure 1.1 ultimately weaken the market for defense products and limit the ability of commercial organizations to invest in basic research, technology development, and transition. Without the influence and lead of commercial companies pushing the state-of-the art for DoD technologies, the military has been forced to rely more heavily on its own technology development and transition capabilities resident within the RDT&E organizations of each service *(Kuizumi, 2006)*. Faced with this reality, the U.S.

government has begun to increase the amount of funding allocated to the services for technology development and transition. Figure 1.2 depicts this increase in research and development funding beginning in 1999 and continuing through 2006 *(Kuizumi, 2006*).

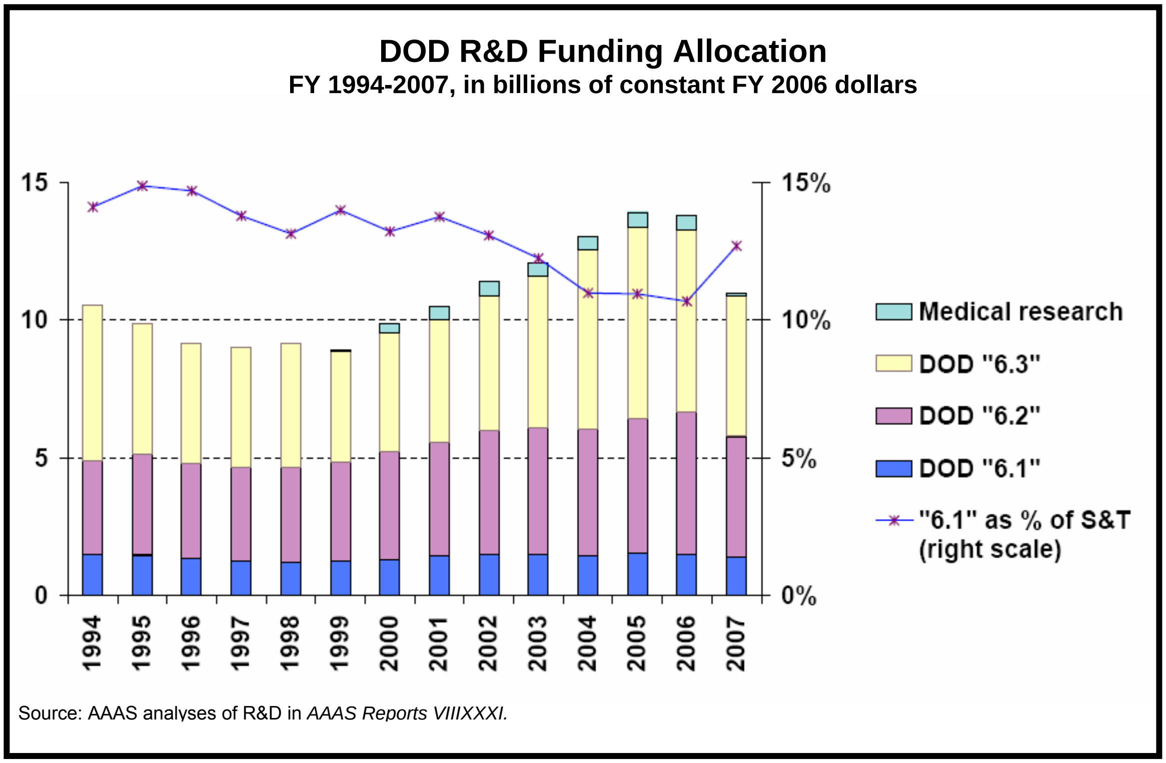

Figure 1.2: DoD Research & Development Funding Allocation FY94-07

The horizontal "6.1" curve in Figure 1.2 shows that, although the total allotment for research and development is rising, the funding appropriated for low-level, basic research has been on a steady decline. In fact, FY2007 reflects a marked drop in the total allocation of technology development funding across the entire DoD. This reduced funding allocation results in a diminished capability to mature basic science into useable technologies for military use.

Given the military's reliance on state-the-art technologies and an eroding capability for U.S. development of those technologies *(Mayer, 2004)*, an alternative strategy is needed in order to maximize the effectiveness and efficiency of the limited dollars allocated for research and development.

B. PURPOSE

The purpose of this thesis is two-fold. The first purpose is to establish a an understanding of the processes used by the Department of Defense (DoD) military services in performing basic research, technology transition, and technology development. This understanding will be achieved through data-gathering and analysis of three high-profile acquisition programs currently being developed by the DoD: the Air Force's Space Radar (SR) Program, the Navy's DD(X) program, and the Army's Future Combat Systems (FCS) program. The second purpose is to identify and propose opportunities in which technology development can be integrated across elements of these three acquisition programs. These new opportunities for technology leveraging will call for the inter-service utilization of DoD research laboratories, technology suppliers, transition processes, performance metrics, and manufacturing assessment strategies.

C. RESEARCH QUESTIONS

The study performed in this thesis is focused on answering this primary question: "Can DoD acquisition programs of a DoD service leverage the technology development efforts of the other services within the DoD?" In order to answer for the primary question, the following related questions must first be answered.

1. What are the common technologies utilized in defense systems?

Specifically, what are the pervasive technologies that are utilized in almost all of the major systems that are being developed within the DoD (e.g., power generation, power storage, propulsion, thermal cycling, environmental hardening, etc.)? The answer to this question will help determine the principal areas in which inter-service technology development can, and should, take place.

2. What are the processes used by each of the services to develop basic technology?

Pertaining to the individual processes employed by each of the DoD laboratories, this question deals with the methods that each of the services employs to characterize and understand a "technology" and to further mature it to create new capabilities and functions for potential military application.

3. What are the processes used by each of the services to transition basic technology into producible, deployable components, and what is the normal sequence of events?

This question deals with the follow-on utilization of the matured technology and its ultimate integration into a component for system application. Although each service performs the technology transition process somewhat similarly (Dobbins, 2004), the subtle nuances must be understood in order to extract the lessons learned and to identify opportunities for potential leveraging.

4. Do the acquiring services develop new technologies through renewed basic research, or is there an established program to retrofit or reuse existing technology?

This question deals with the degree to which the DoD services reuse existing technologies. The cost, schedule, and performance of a technology are directly attributable to its initial maturation level prior to any DoD service laboratory investment. Understanding each service's perspective on technology re-use will provide greater insight into the technology maturation process.

D. BENEFITS OF STUDY

This study will identify and propose opportunities to integrate technology development across three high-profile acquisition programs for the Air Force, Army, and Navy. These proposed technology development opportunities should improve schedule efficiency and cost-effectiveness during the RDT&E process. This research effort will also describe how the consolidation of technology

development could benefit the U.S. industrial base through increased opportunities for development funding and a new capability to leverage individual supplier technologies across the DoD.

E. SCOPE AND METHODOLOGY

1. Scope

The scope of this thesis covers four areas of study. (1) Background of technology development within the DoD, (2) determination of the key aspects of three high-profile acquisition programs currently in development within the DoD, (3) in-depth look at each service's RDT&E organization responsible for technology development and follow-on technology transition, and (4) aggregation of the technology requirements of the three DoD programs and allocation of the most-suitable S&T Lab to perform the necessary development work.

First of all, this study investigates the background of technology development within the DoD with respect to the development motivations and goals shared by the varying defense services, and highlights the need to institute an inter-service technology development strategy to mitigate common cost, schedule, and industrial base issues.

Second, this study focuses on determining the key aspects of the SR, DD(X), and FCS programs currently in development within the DoD. Given the fact that these programs will become the beneficiaries of the leveraging opportunities identified in this thesis, a review of each program's technology development plan and an in-depth assessment of each program will facilitate a true understanding of the each program's needs.

Third, aimed at developing an acute sense of the purpose, direction, and operating parameters under which each S&T Lab organization exists, this research takes an in-depth look at each service's RDT&E organization responsible for technology development and follow-on technology transition.

Finally, this research aggregates the technology requirements of the three DoD programs and allocates the most-suitable S&T Labs to perform the necessary development work.

2. Methodology

A process for the research and analysis of this study follows.

a. Review the detailed requirements for the three high-profile DoD acquisition programs. Review program Mission Need Statements (MNS), Technical Requirements Documents (TRD), System Specifications, Program Management Reviews (PMR), and other program specific documentation. Identify Key Performance Parameters (KPP's) and critical technologies. Interview program managers and internal technical leadership to understand current vector and technology development methodology.

b. Review organizational Concept of Operations (CONOPs) for various DoD S&T organizations. Review the current S&T development and technology transition methodology for each program. Assess technology development specifications and documents. Interview S&T program managers, team members, and agency leads to validate methodologies.

c. Correlate the information gathered to identify pervasive, cross-cutting, inter-service S&T leveraging opportunities that will most effectively provide transitioned technologies to each of the three DoD programs highlighted for this thesis.

F. ORGANIZATION OF STUDY

This thesis is organized into five chapters. Chapter I provides a detailed discussion on the importance of technology development, its role in acquiring new systems, and the reasons for an integrated approach for all DoD systems. Chapter II focuses on creating a detailed program baseline for each of the services premier acquisition systems. This baseline highlights each program's mission, Key Performance Parameters (KPP's), Technical Requirements, Technology Freeze Dates, Financial Information, and planned deployment schedule. This information forms the foundation for determining how best to integrate technology development across the DoD laboratories. Chapter III

focuses on creating a detailed operational baseline for the S&T laboratories that provide the primary technology development for each of the services. This baseline will consist of information pertaining to technology leverage opportunities among the services, technology maturation and transition experience, funding allocation processes, integration with DoD requirements, and provide a detailed assessment of each services technology development capabilities. The baseline established in this chapter will also be composed of past successes, current research and development initiatives, and other information critical to understanding the key capabilities of each technology development organization. Chapter IV focuses on allocating the previously identified technology development requirements to the laboratory organizations best suited to achieve the programmatic requirements. Finally, Chapter V provides a discussion of the study's conclusions and a recommendation to coordinate these opportunities to senior DoD leadership for review and potential implementation.

II. PROGRAM REQUIREMENTS FOR NEXT GENERATION DOD SYSTEMS

A. INTRODUCTION

The DoD is currently in the early stages of developing the three critical military systems to employ during the next generation of global combat. The Air Force is developing the Space Radar (SR) program; the Navy is developing the DD(X) 21st century Destroyer program; and the Army is developing the Future Combat Systems (FCS) program. In this chapter, an in-depth technological and programmatic assessment of the three acquisition programs provides key insight into the broad functional requirements of each program in addition to the technical requirements that each system must satisfy. This assessment of technology needs for the Space Radar, DD(X), and FCS programs provides the foundation for an inter-service technology leveraging capability.

B. AIR FORCE SPACE RADAR SYSTEM

1. Mission Thread & Acquisition History

The Space Radar (SR) system, as envisioned by the Air Force, is an operational radar reconnaissance satellite system *(Steinhardt, 2000)*; an artist rendering is shown in Figure 2.1. It is a new, major defense acquisition program delegated in 2001 to the Air Force by then Secretary of Defense, Mr. Donald Rumsfeld *(Steinhardt, 2000)*. Originally named the Discoverer II program in 1998, the program's primary charter at that time was to develop the capability to track mobile ground targets from space, to be achieved by the year 2008 *(Steinhardt, 2000)*. This original program was a joint initiative of the Air Force, the Defense Advanced Research Projects Agency (DARPA), and the National Reconnaissance Office. Although the program had reached the Preliminary Design Review (PDR) milestone, it was cancelled due to unrealistic requirements, lack of future funding source, and the absence of a clearly defined transition plan to operational use *(Tirpak, 2002).* Upon further review, Mr.

Rumsfeld concluded that a space-based radar system could still provide a significant military advantage on the battlefield and, in 2001, approved the Space Radar system as a new, major defense acquisition system *(Tirpak, 2002)*. Supporting this decision, Mr. Peter Teets (Undersecretary of the Air Force and the Executive Agent for Space) stated, "[Space-Based Radar] is a really important new program coming on line to serve the intelligence community and the warfighting community . . . In some ways, it will be more important in the kinds of conflicts we're now involved in than it would be in major-war operations. It will be an important element in our efforts to achieve horizontal integration—merging all kinds of intelligence, surveillance, and reconnaissance information from all sources and getting it directly to our fighting forces wherever they are, and in near-real time." *(Canaan, 2004)*.

Figure 2.1: Artist Rendering of AF Space Radar System
(From: Tirpak, 2000)

The main objective of the new Space Radar program is to field, beginning in 2008, a space-borne capability for theater commanders to track moving targets on the ground and on the open-ocean. The commander of the Space and Missile Systems Center, Lieutenant General Brian A. Arnold, views this program as a critical enabler to the U.S. warfighting capability: "This system will complement other manned and unmanned systems . . . During peacetime, obviously, it would be great for intel preparation of the battlefield. ... During wartime, especially in high-threat areas, it may be the only thing you can get into an area." *(Tirpak, 2002)* A principal advantage of utilizing a radar in space is having the ability to "see" through atmospheric aberrations (e.g., clouds, sand storms, hurricanes, etc) in any type of weather, day or night. In contrast, radar-equipped aircraft and other surveillance tools require dominance of the airspace in and around the area of interest to collect the vital radar data. Such a requirement would obviously limit the amount of data that can be obtained from non-friendly countries as U.S. forces are not permitted to violate their airspaces. The Space Radar program avoids this violation by utilizing the space environment, an internationally sovereign-free zone, to provide the DoD with high resolution terrain information, advanced geospatial intelligence, and surface moving target indication. This information will help military analysts gain a better understanding of what is occurring in specific locations and provide the military with an unprecedented advantage for peacetime surveillance and wartime theater engagements.

2. Key Requirements and Capabilities

Based upon recent setbacks in developing critical programs similar in scope to Space Based Radar, the Air Force has primarily focused the program's resources on continued requirements development, technology risk reduction, concept exploration, and cost feasibility *(Canaan, 2004).* Mr. Teets provided a very succinct reasoning for this approach: "It's much better to catch problems and retire risk early. Programs get into cost and schedule problems because they aren't structured properly in the first place." *(Canaan, 2004)* Within this

framework of risk-reduction, the current Space Based Radar (SBR) program aims to develop an Information, Surveillance, and Reconnaissance (ISR) system capable of providing Ground Moving Target Indication (GMTI), Synthetic Aperture Radar (SAR) imaging, and Digital Terrain and Elevation Data (DTED) over a large portion of the Earth on a near-continuous basis. However, with the program still in the design stage, the baseline system definition continues to evolve. Furthermore, the system development strategy is to use the spiral development approach with the first operational unit, Increment 1, deployed in 2010-2012 *(Roberts, 2003)*.

Figure 2.2 provides the primary capabilities of this first increment of the Space Radar system. The Ground Moving Target Indication (GMTI) Collection and Open Ocean Surveillance capabilities will provide theater commanders with real-time tracking and location information for enemy targets on the ground and on the open ocean. The High Resolution Terrain Imaging (HRTI) capability will yield critical information regarding the type and consistency of battlefield terrain. The Digital Terrain Elevation Data system will augment the HRTI capability by providing terrain depth data. The Advanced Geospatial Intelligence system will provide world-wide tracking capability via the on-orbit networking of Space Radar's satellites. The tertiary capabilities listed in Figure 2.2 describe the additional benefits enabled by the systems primary capabilities.

Primary Space Radar Capabilities

- Ground Moving Target Indication Collection Capability
- High Resolution Terrain Imaging Capability
- Advanced Geospatial Intelligence Capability
- Open Ocean Surveillance Capability
- Digital Terrain Elevation Data

Tertiary Space Radar Capabilities

- Continuous surveillance of cruise missile sized targets
- Identification Friend or Foe (IFF) of cooperating aircraft
- Communications to allow control of the air battle within the surveillance area
- Communications to supply battlespace visibility to shooters and command centers
- Simultaneous combinations of sector search, attack planning, attack support, and low-resolution synthetic

Figure 2.2: Space Radar Key Capabilities

3. Critical Technologies

Figure 2.3 provides a perspective on the technologies that the Space Radar program office, along with supporting technical agencies, have identified as being “critical technologies.” These are defined as those technical or scientific products that absolutely must be integrated into the Space Radar system in order to ensure the system provides the baseline functionality defined in Figure 2.2 (*Sullivan, 2006)*.

Space Radar Critical Technologies

- Electronically Scanned Array (ESA)
- On-board Processor
- Information Management System
- Ground Moving Target Indication (GMTI) System
- Advanced Solar Cells
- Lithium Ion Batteries

Figure 2.3: Space Radar Critical Technologies

The technologies shown in Figure 2.3 are critical to the successful demonstration and deployment of a Space Radar capability. The description of these necessary technologies follows.

a. Electronically Scanned Array (ESA)

An Electronically Scanned Array (ESA), also known as active phased array radar, is a revolutionary type of radar whose transmit and receive function is provided via numerous small transmit/receive (T/R) modules. This technology will provide the SR system with short to instantaneous (millisecond) scanning rates and an immobile, less mechanically complex system than conventional radar designs (Sullivan, 2006). This ESA technology will also yield the ability to track and engage a large number of targets while functioning as a radio/jammer with simultaneous air and ground modes (Sullivan, 2006)

b. On-Board Processing

The Space Based Radar On-Board Processing (OBP) technology will be comprised of the radiation-hardened microcircuitry, and associated software, that will combine all input data and create Ground Moving Target Indicator (GMTI) detections, Synthetic Aperture Radar (SAR) image, and Digital Terrain Elevation (DTED) data (Underwood, 2005). This processing technology will also combine and leverage existing and future satellite sensor technology developments (e.g., more data, increased bandwidth, new processing algorithms, etc.) to provide a reliable, cost-effective, real-time processing capability in a space environment.

c. Information Management System

The Information Management (IM) system for Space Radar will be a critical factor in the satellite network's data ingest, processing, and dissemination cycle. The SR system must reliably archive processed data and facilitate multiple, concurrent database queries (Sullivan, 2006). The goal for SR's IM system development is the establishment of a common operating

architecture for wartime theater and peacetime information management. The development process for this IM system will require the identification of technical deficiencies in data archiving processes as well as the creation and implementation of several prototype architectures for national and tactical information management. An efficient IM system for Space Radar will enable the creation of a comprehensive picture of the Battlespace.

d. Ground Moving Target Indication (GMTI) System

Space Radar will exploit an extremely advanced, all-weather, GMTI capability to survey wide ocean and ground areas to detect, target, and track mobile troops, vehicles, and weapons. This capability will be made possible through the implementation of highly evolved GMTI surveillance hardware and software. The evolution of these components will require technology development in the areas of Synthetic Aperture Radar processing (detection and all weather capability), Space-Time Adaptive Processing algorithms (for rejection of ground clutter and other extraneous information), integration of the detected ground targets with map underlays, and development of GMTI surveillance strategies (Steinhardt, 2000). These components form the basis of Space Radar's primary capabilities and must be developed with a focus on technical performance and precision.

e. Advanced Solar Cells

With a requirement to continuously track and target objects on the ground, the power ingest and distribution system for SR is of paramount importance. The solar cell component of the spacecraft is responsible for generating electricity through photovoltaic conversion, which is then used by the vehicle to power normal operations. Although several breakthroughs (SOLAR, 2000) have been made in regards to the efficiency of these solar cells, more development work is required to enhance the technology and allow for appropriate engineering and design trades to be made.

f. Lithium-Ion Batteries

Early in the concept development phase of the SR program, engineers surmised that in order to satisfy the continuous tracking and targeting requirement, high power batteries would be needed to conduct nighttime operations when the Sun would not be shining on the solar cells to provide direct power. Lithium Ion batteries have been identified as the only viable energy storage technology capable of meeting this nighttime operations requirement (Underwood, 2005). Although these batteries have demonstrated a significant weight advantage over presently used Nickel Hydrogen batteries, improvements in cycle and calendar life are required to make this technology viable for the Space Radar program. There are also fundamental questions pertaining to the stability of the Lithium-Ion materials, corrosion, and degradation reactions that must be answered before this technology can be viewed as a candidate for integration into the SR system.

Although low-level risk reduction and technology development analysis efforts are currently underway at the Air Force Research Lab (AFRL) for each of the SR critical technologies, a leveraged inter-service technology development plan could potentially free program funding from some development areas and allow the program manager to apply those funds for further risk reduction and development in others. The opportunities for such leveraging will be analyzed in detail in Chapter IV.

4. Schedule & Technology Freeze Dates

Figure 2.4 depicts the SR program acquisition and development schedule. In this thesis, all critical technologies are assumed to be developed and ready for integration prior to the Critical Design Review, which, for the Space Radar program, occurs in the 4th quarter of FY2010. The period in which all technology development ceases is called the Technology Freeze Date (TFD) and is shown in Figure 2.4. Chapter IV provides more discussion of SR’s TFD.

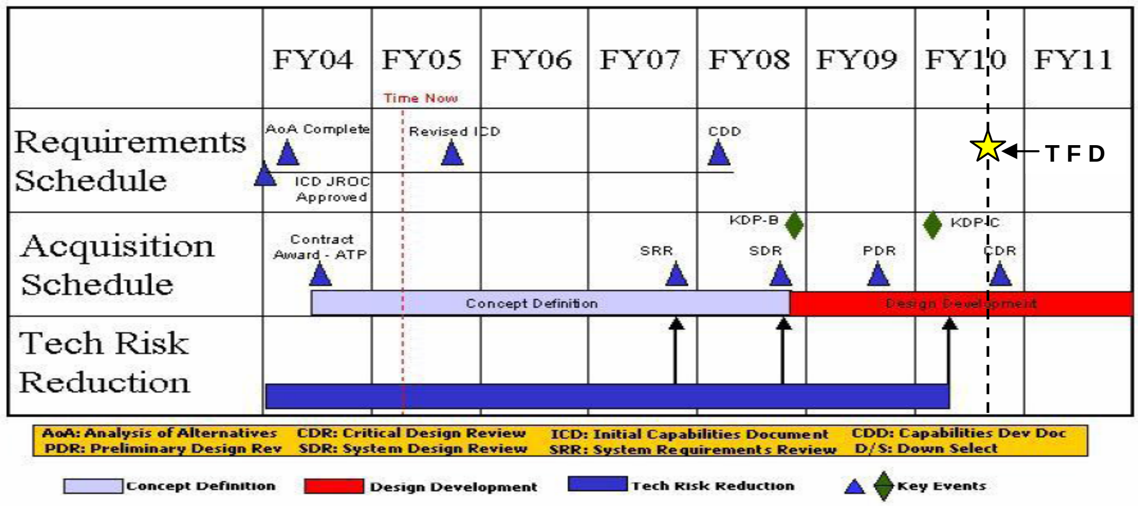

Figure 2.4: Space Radar Development Schedule
(From: Department of the Air Force, 2006)

C. NAVY DD(X): 21ST CENTURY DESTROYER PROGRAM

1. Mission Thread & Acquisition History

The DD(X) destroyer, also known as the DDG-1000 Zumwalt, is the lead ship in a class of next-generation, multi-mission surface combatants tailored for land attack and littoral dominance. Figure 2.5 provides an artist rendering of the vessel. This advanced sea vessel contains integrated technologies and capabilities designed to defeat current and projected threats as well as to improve battle force defense. Bringing revolutionary improvements to precise time-critical strike and joint fires for future Expeditionary and Carrier Strike Groups, this advanced destroyer will fulfill multiple missions for theatre combat. The DD(X) destroyer expands the battlespace by over 400%; has a radar cross section orders of magnitude smaller than its actual size; and is as quiet as a LOS ANGELES Class submarine *(Peterson, 2005)*. This multi-mission destroyer will also enable the transformation of land operations. Naval joint fire support and ground maneuver concepts of operations (CONOPs) will be transformed by the DD(X)'s on-demand, persistent, time-critical strike capability. This capability will

ultimately free ground and other allied forces to focus on more difficult targets at greater ranges. The DD(X) destroyer will provide a dominant forward presence while operating either independently or as an integrated component of a naval, joint, or combined expeditionary force.

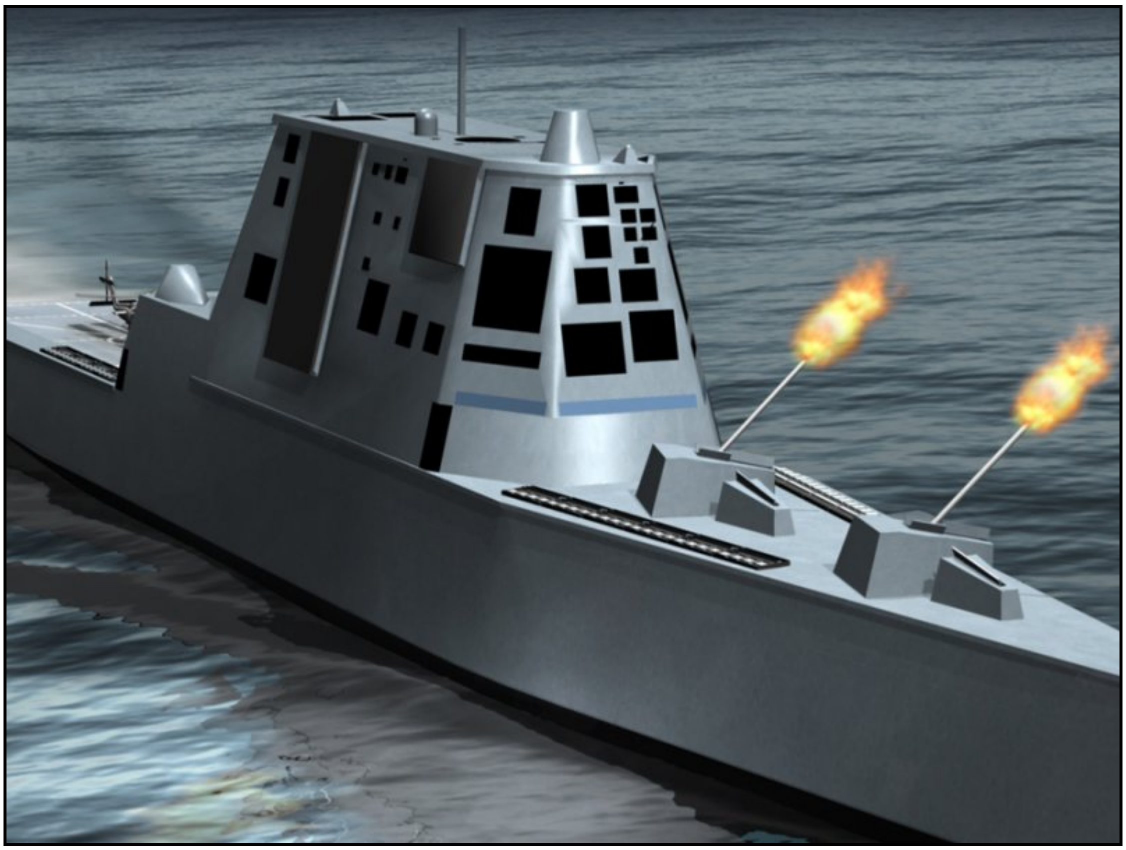

Figure 2.5: Artist Rendering of DD(X) Destroyer
(From: Child, 2006)

In 1994, the U.S. Navy created a program to transform the U.S. Navy's surface combatant fleet. This program called for the development of a new family of ships that would project force more rapidly, engage in conflict more effectively, and be far less expensive to operate than the current fleet vessels. The flagship for this new family of ships is identified as the DD(X) destroyer. After several years of study of alternative concepts, in April of 2002 a system design and development team led by Northrop Grumman Ship Systems (NGSS)

was chosen to manage a three year risk-reduction effort and to take the reins as the lead design component for the program. This risk-reduction effort was primarily focused on lowering the technical risk of the many transformational technologies that comprised the vision of the DD(X) and the development of a credible integration plan to implement these technologies on the destroyer. It was also in this phase of the program that the development team added multiple land and sea-based prototypes as its primary technical risk mitigation method.

In November 2005, the Department of Defense authorized the DD(X) Destroyer program to enter the detailed design phase of the acquisition, with fabrication commencing in 2007 and the first ship delivered to the Navy in 2011.

2. Key Requirements and Capabilities

In his testimony before the House of Representatives, Chief Naval Officer Admiral Vern Clark stated,

> The DD(X) will be a technology engine. It will inform and educate us in ways we don't understand today the places it will be able to go because of its stealthy design will change the nature a potential enemy. Its low radar cross section, stealth, and low acoustic signature will change the nature of the missions for surface combatants and the manner by which we operate the ship. People don't realize how much of a driver for change that DD(X) will be. *(Peterson, 2005)*

Designed to reduce crew size and yield a significant combat advantage, the DD(X) will incrementally integrate new technologies for successive builds and other future naval vessels. Advanced combat systems and networking capabilities are some of the technologies that will be integrated in future builds to produce a survivable and capable near-land platform for the 21st century.

As Figure 2.6 shows, the current DD(X) Destroyer design features a composite deckhouse and a Wave-Piercing Tumblehome Hull displacing nearly 14,000 tons. This design also features two Advanced Gun Systems (AGSs) with a combined magazine capacity of approximately 750 rounds of long-range land attack and conventional munitions (Francis, 2004). Each of these technically

advanced systems, optimized for ground attack, will consist of a single-barrel 155-mm gun supplied from an automated magazine. The DD(X) Destroyer is an Advanced Vertical Launch System (AVLS) with 80 cells to host Tomahawk Land Attack Missiles, Standard Missiles (SM2-MR) for local air defense, Evolved Seasparrow Missiles to engage both airborne and seaborne threats, and Vertical Launch Anti-Submarine Rockets to engage and mitigate submarine threats. Two 40-mm Close-In Gun Systems are also designed into the DD(X) system to enhance defense against air and surface threats *(Francis, 2004)*.

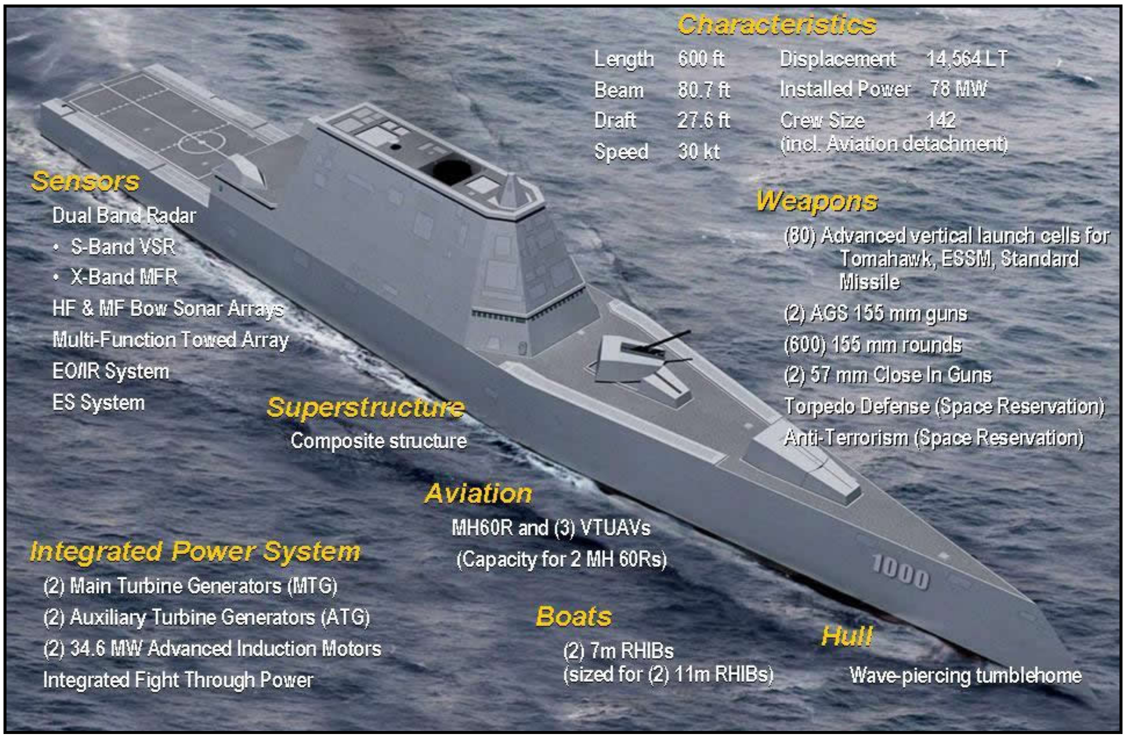

Figure 2.6: DD(X) Key Specifications
(From: Peoships, 2003)

The DD(X) Destroyer will employ a maintenance strategy that focuses on allowing sailors to concentrate on war-fighting tasks and skills rather than on ship maintenance and preservation. The ship will also utilize an extensive automated damage control system, integrated with an optimally manned damage control organization to quickly suppress and extinguish fires and control their spread. The DD(X)'s integrated power system will allow sharing of electrical power

between propulsion motors and other electrical requirements such as combat system and auxiliary services. The new Dual Band Radar suite and the Integrated Undersea Warfare System will provide state-of-the-art battle space surveillance, while advances in survivability and an innovative computer processing capability for the ships operating systems will allow a reduction in crew size. Figure 2.7 summarizes the primary DD(X) capabilities.

Primary DD(X) Capabilities

- Persistent Presence Capability
- 30 Knot Sustained Speed
- Cruise Missile & Small Boat Defense
- Periscope and Floating Mine Detection
- Interoperability
- Low Radar Cross Section
- Precision Strike
- Volume Fires

Figure 2.7: DD(X) Key Capabilities

3. Critical Technologies

To develop and test the DD(X)'s most important functions, the Navy is building ten engineering development models (EDMs) that represent the ship's most critical technologies. Figures 2.8 and 2.9 describe the EDM's in detail.

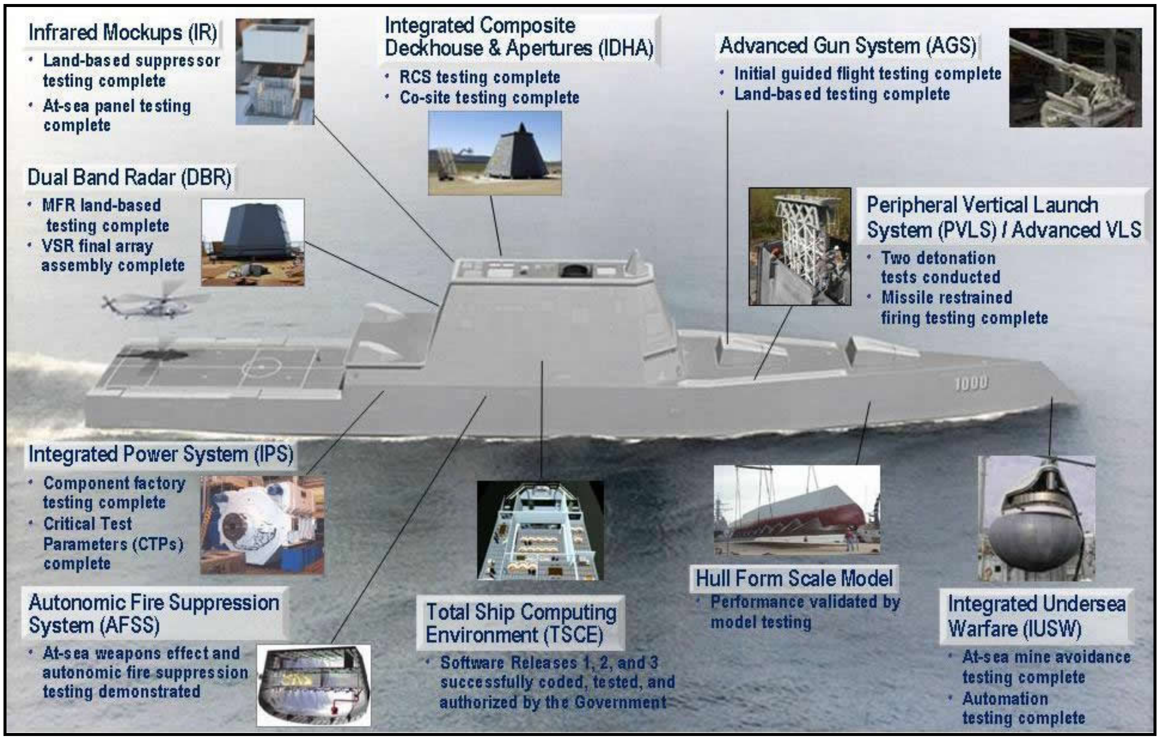

Figure 2.8: DD(X) Engineering Development Models
(**From: Peoships, 2003)**

<u>DD(X) 21st Century Destroyer Critical Technologies</u>

- Advanced Gun System
- Autonomic Fire Suppression System
- Dual Band Radar
- Hull Form
- Infrared Mockup
- Integrated Deckhouse and Apertures
- Integrated Power System
- Integrated Undersea Warfare System
- Peripheral Vertical Launch System
- Total Ship Computing Environment

Figure 2.9: DD(X) Critical Technologies

a. Advanced Gun System

The DD(X) advanced gun system is an unmanned, large caliber gun system developed to support land attack missions by striking specific targets or providing ground troops with suppressing fire. The current design reflects a dual-gun configuration with approximately 300 rounds in each gun magazine. An auxiliary magazine also holds 320 rounds for additional munitions when needed. Given that this system must autonomously strike several-land based targets from long distances, the design must be technically sound and provide a long-range projectile capability *(Francis, 2004)*.

b. Autonomic Fire Suppression System

Designed to reduce the manning and time needed to maintain ship-board fires, this system employs new technologies such as flexible hosing, nozzles, and sensors to autonomously control fire damage. This system is critical for meeting performance parameters for ship survivability and manning levels *(Francis, 2004)*.

c. Dual Band Radar

The dual band radar system continuously monitors both airborne and surface activities, conducts environmental mapping, and guides weaponry to targets. This radar system is composed of two radar subsystems: a multifunction radar and a volume search radar. The multifunction radar monitors airspace at near-earth levels, searching for low-flying threats, while the volume search radar provides information on missiles, aircraft, or other air-borne threats in the open sky (Francis, 2004).

d. Hull Form

The DD(X) will employ advanced materials and a design that will reduce its radar cross section. Additionally, the ships hull form must support ship performance parameters for survivability, operations in various ocean environments, and speed.

e. Infrared Mockup

The Infrared Mockup is the name for a group of technologies that will reduce the heat signature of the DD(X) hull. Using material treatments, passive air cooling, and a technique for sheeting water over the ships hull, this group of technologies will lower the amount of heat collection on the DD(X) and reduce the ship's visibility to infrared missile and radar sensors.

f. Integrated Deckhouse and Apertures

The integrated deckhouse and apertures compose the superstructure on the ship deck; they are the openings in which the ships radar, sensor farm, and communications equipment are housed. The design of the location and size of these openings must minimize radar cross section signature and radio crosstalk.

g. Integrated Power System

The integrated power system centrally generates and distributes power for all the ships functions, including the propulsion engines. Consisting of three primary components (turbine generator sets, power distribution system, propulsion motors), the power system provides for increased flexibility in power use and will allow the future integration of high energy laser weapons.

h. Integrated Undersea Warfare System

This software-intensive, autonomous integrated undersea warfare system provides for a combined mine avoidance and submarine warfare capability.

i. Peripheral Vertical Launch System

The Peripheral Vertical Launch System (PVLS) provides an innovative launch capability. Unlike traditional deck-mounted missile systems,

the PVLS system uses a missile launcher and housing strategically located within the ship to improve survivability and designed to prevent damage by directing explosions away from the ship.

j. Total Ship Computing Environment

This software-based technology provides a single computing environment in which ship functions can be integrated and controlled to speed command, while reducing manning. The system helps to achieve manning, input compatibility, and survivability performance parameters by actively managing the speed of data delivery throughout the ship, providing defense against information security threats, autonomously tracking and engaging targets, contributing to ship threat response times, and greatly reducing the time required to recover after equipment failure.

D. SCHEDULE AND TECHNOLOGY FREEZE DATES

Although normal acquisition policy dictates that engineering and technology development be completed prior to the Critical Design Review (CDR) and build decision, many leaders in the naval community view concurrent technology development and ship production as being necessary and of low risk. In his response to the negative review received from the Government Accounting Office (GAO) *(Francis, 2004)* , USN Captain Glenn F. Lamartin provided a perspective on the schedule for technology maturing for naval programs: “The ability of DD(X) to deliver revolutionary capabilities to the fleet with reduced crew necessitates some element of development and production risk. Given the long production lead time in shipbuilding, the Navy believes it is appropriate to undertake a reasonable amount of risk in the DD(X) lead ship, in order to deliver technological benefits to the rest of the class. The DD(X) schedule and the execution of the EDMs in time for ship installation, which for shipbuilding programs, is the most relevant point of reference for technology maturity” *(Lamartin, 2004)*.

With this perspective on technology insertion, Figure 2.10 shows that the Navy has identified mid-2011 as the TFD for the DD(X) program.

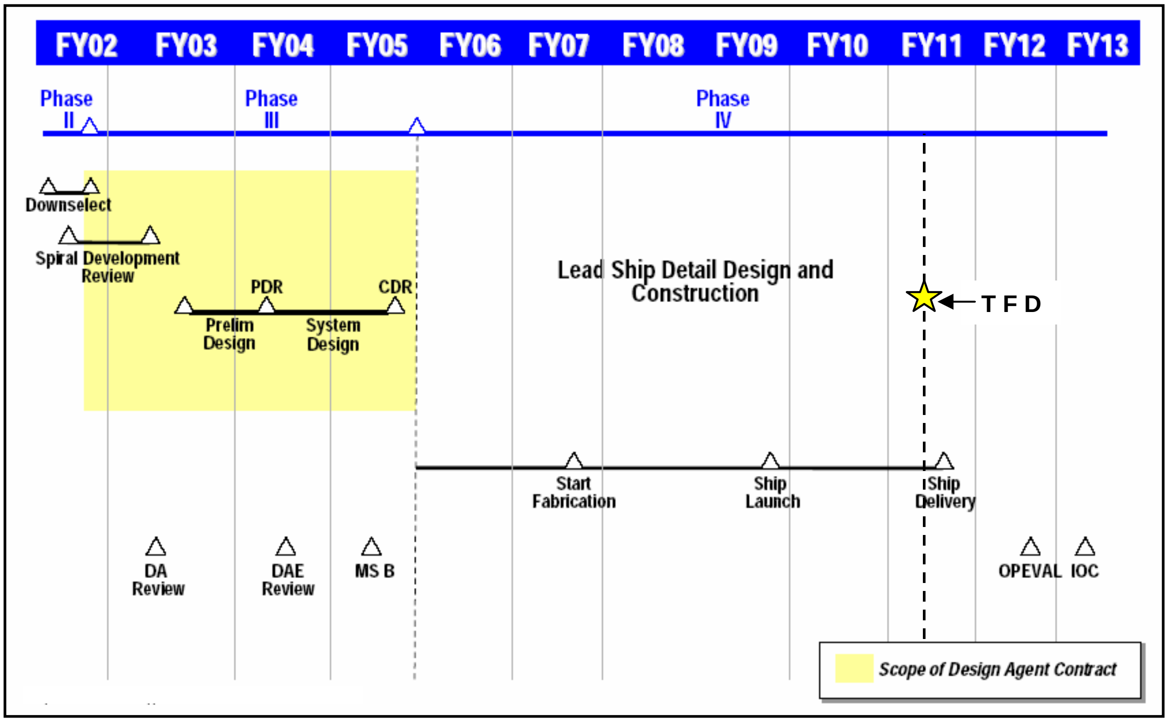

Figure 2.10: DD(X) Development Schedule
(From: Peoships, 2003)

E. ARMY FUTURE COMBAT SYSTEMS (FCS)

1. Mission Thread & Acquisition History

The Future Combat Systems (FCS) is the Army's premier program for transforming the way in which soldiers and Army infantrymen prosecute and engage in global conflict *(Feikert, 2005)*. This program is a networked system of systems that uses advanced communications and technologies to integrate the soldier with groups of manned and unmanned platforms and sensors, illustrated in Figure 2.11. Agile and lethal, the FCS will provide the tactical formations required to fulfill the Army's vision for a "Future Force": organized, manned, equipped, and trained to be strategically responsive, deployable, versatile, lethal, survivable, and sustainable across the entire spectrum of military operations from

major theater wars through counter terrorism to homeland security *(Feikert, 2005)*. FCS tactical formations will enable the Army to rapidly track, engage, and succeed on the battlefield. The FCS force will be lighter, more mobile, and more lethal, consisting of robotic reconnaissance vehicles and sensors, tactical mobile robots, mobile command, control and communications platforms; networked fires from futuristic ground and air platforms; and advanced three-dimensional targeting systems operating on land and in the air *(Cartwright, 2004)*. The ultimate goal of the FCS program is to mature and demonstrate new and improved combat vehicle and automotive technologies to enable transformation of the Army to the Future Force.

The FCS program uses a streamlined, integrated three-phase acquisition strategy to achieve transformation by 2010. The three phases are: Concept and Technology Development (CTD), System Design and Demonstration (SDD), and System Production.

Figure 2.11: Future Combat Systems Component Network
(From: TACOM, 2003)

In March 2002, the Defense Advanced Research Projects Agency (DARPA) and the Army announced the selection of a Lead Systems Integrator team composed of the Boeing Co. and Science Applications International Corp. (SAIC). This team was chosen to manage the Concept and Technology Development phase of the FCS program, supporting the Army's development of the concept design, organization and operational structure, and performance specifications for the program. The system of systems architecture and the overarching development approach employed by the Boeing & SAIC team would enable significant opportunities for technology insertion, incorporation of best business practices, and ultimately ensures the sharing of an integrated process by all organizations involved.

In May 2003, the Department of Defense approved the Army's FCS Operational Requirements Document (ORD) and subsequently signed a memorandum that would move the Future Combat Systems (FCS) program from the Concept and Technology Development phase into the $14.9 billion System Development and Demonstration (SDD) phase. During this phase, The Army and the LSI Team began design and development of FCS, with a first demonstration of the systems capabilities planned for FY08. The third phase of the program, System Production, is slated to begin in 2009, with Full Operating Capability (FOC) scheduled for FY13.

2. Key Requirements and Capabilities

The core of the FCS program is a highly integrated structure of 18 manned and unmanned (MUM), air and ground maneuver, maneuver support, and sustainment systems. Joined together by a distributed network, this integrated structure supports the soldier and acts as a cohesive, unified force in the Joint warfare environment. The network uses a Battle Command architecture that combines networked communications, network operations, sensors, battle command system, training, and reconnaissance and surveillance capabilities to enable situational understanding and operations at a level of synchronization not

achievable in current network centric operations. Figure 2.12 describes the physical architecture of the FCS and the various vehicles and technology elements that comprise the system.

Future Combat Systems: Physical Implementation

- Unattended Ground Sensors (UGS)
- Attended Munitions
    - Non-Line Of Sight–Launch System (NLOS-LS)
    - Intelligent Munitions System (IMS)
    - Unmanned Aerial Vehicles (Four Classes)
- Unmanned Ground Vehicles (3 Classes)
    - The Armed Robotic Vehicle (ARV)
    - Small Unmanned Ground Vehicle (SUGV)
    - Multifunctional Utility/Logistics And Equipment (MULE) Vehicle
- Eight Manned Ground Vehicles
- The Network
- The Soldier

Figure 2.12: FCS Physical Implementation

Figure 2.13 describes the key capabilities and performance parameters delineated within the FCS Operational Requirements Document (ORD). These capabilities are required by the war fighter and provided through the successful development of the technologies shown in the next section.

Primary FCS Capabilities

- Situational awareness that enables superior knowledge and survivability for the Soldier.
- Networked information and advanced, seamless command and control
- Increased agility to get the right force to the right place at the right time.
- Reduction in traditional logistics footprint for fuel, water, ammunition, and repair parts by 30-70%.
- Joint, networked 'system of systems' that is comprised of 18 manned and unmanned ground and aerial vehicles and sensors connected via an advanced communications network.

Key Operational Parameters

- Joint Interoperability
- Networked Battle Command
- Networked Lethality
- Transportability
- Survivability
- Sustainability & Reliability
- Training

Figure 2.13: FCS Key Capabilities

3. Critical Technologies

The FCS system is a complex network of manned and unmanned systems that will rely on the maturation of multiple key enabling technologies. In an effort to reduce the technical risk inherent with large-scale technology development, the Boeing and SAIC development team identified the technologies necessary to implement the program, based upon the ORD, and further prioritized them by criticality and mission need. This prioritization, which ranged from the lowest priority (level 4) to the highest (level 1), allowed the development team to focus its attention on developing the high-priority program technologies before they focused on those with a lower priority. The level 1 or “critical” FCS technologies are shown below in Figure 2.14 and now discussed.

<u>FCS Critical Technologies</u>

- MEMS Antenna (ESA phase shifting switch)
- Advanced Power Storage Technologies
- Software Defined Radios (JTRS, SUO)
- Silicon Carbide Switches
- Low Cost Composites

Figure 2.14: FCS Critical Technologies

a. MEMS Antenna (ESA Technology)

The FCS will employ an Electronically Scanned Array (ESA) to electronically change the direction of the antenna to scan or broadcast over a broad range without physically moving the antenna. This ESA system will be implemented into the antenna using micro-electro-mechanical systems (MEMS) technology, which allows for the execution of complex functions on a size-scale orders of magnitude lower and at far less power than discrete circuits. Deployed onto various FCS platforms, this technology will allow the vehicles to transmit and receive data over larger distances, continually track multiple objects in different directions, and permit the use of a smaller energy storage capacity through the MEMS technologies diminished power usage *(Sotirin, 2003)*.

b. Advanced Power Storage Technologies

The FCS vehicle fleet will be forced to travel long distances while continually tracking and performing power-intensive data transmit and receive operations. To meet this requirement, the FCS development team currently plans to implement Lithium-Ion battery technology into its vehicles. This battery choice is based upon the batteries extreme energy density, comparable light-weight, and extremely rapid recharge capability *(Francis, 2005)*. Although used in many commercial applications, Lithium Ion batteries must still be further developed and tested for the harsh environment and operating conditions in which the Army would be using the batteries.

c. Software Defined Radios

This software radio technology will provide the FCS program with revolutionary software-programmable tactical radios that will provide the capability to transmit and receive voice, data and video communications, as well as ensure a common communication platform across the joint battlespace. Current radio systems lack commonality and do not have enough bandwidth to manage the types and frequency of data required of the FCS network *(Francis, 2005)*.

d. Silicon Carbide Switches

FCS vehicles will be required to demonstrate increase in mobility, survivability, and lethality while reducing logistics burdens. To meet this requirement, hybrid electric power architectures and management strategies must be employed. Silicon Carbide Switches provide the basic building block to the hybrid electric components and technologies needed to facilitate these power architectures for FCS vehicles *(Francis, 2005)*.

e. Low Cost Composites

Affordable, lightweight armor for lightweight combat platforms is a critical issue for FCS and the Future Force. With the vehicles becoming smaller and more agile, it is imperative that they be protected from enemy munitions and ordinance without increasing the overall vehicle weight. The FCS development team is currently assessing the capabilities of multiple composite technologies to determine a baseline technology that can be modified and further developed to meet the FCS weight and vehicle protection goals *(Sotirin, 2003*).

4. Schedule and Technology Freeze Dates

Although originally scheduled to provide an initial demonstration capability in FY2010, Army officials announced plans on 22 July 2004 to accelerate the delivery of selected future combat systems components to FY2008. This acceleration required more experimentation and evaluation to prove and mature

the technology concepts and components, and a new methodology for systems development. Recognizing this need for a new development plan, the Army adopted a plan to incrementally "Spin-Out" (SO) select technologies with the FCS deliveries every two years and gradually add technology and capability with each delivery as the system approaches FOC in 2013 *(Francis, 2003)*. The schedule in Figure 2.15 highlights the Army "Spin-Out" development methodology, and the various Technology Freeze Dates that support it.

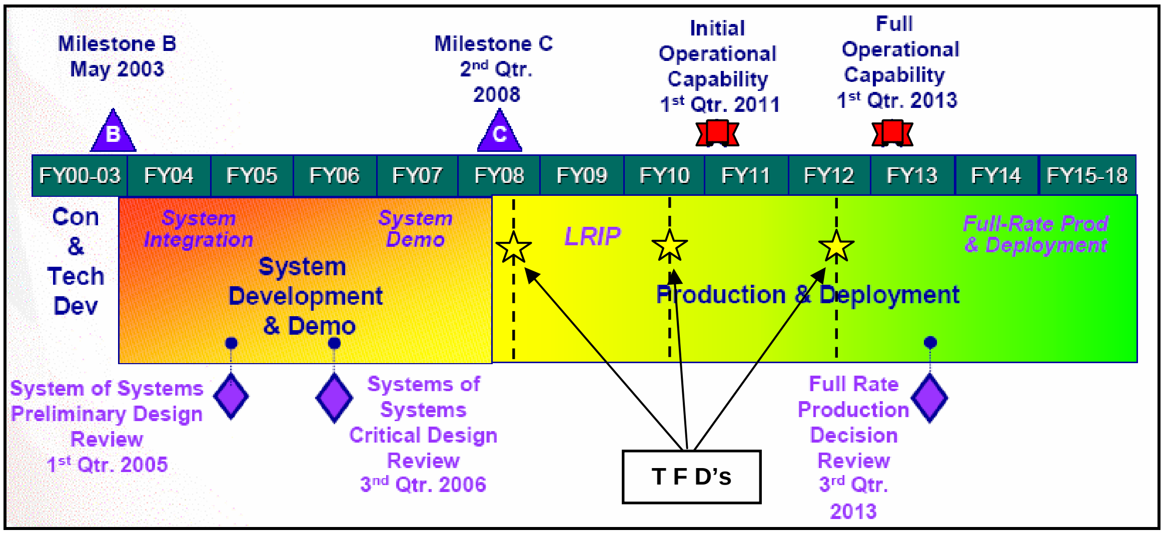

Figure 2.15: FCS Development Schedule
(From: Feikert, 2005)

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III. DOD RDT&E TECHNOLOGY DEVELOPMENT REVIEW

A. INTRODUCTION

This chapter continues on the path to identification of technology leveraging opportunities by assessing the RDT&E organizations responsible for delivering the fundamental technologies required for the three next-generation acquisition systems. Each of these special RDT&E organizations, or Science & Technology Laboratories (S&T Labs), has a core set of technology development competencies and focus areas. Irrespective of the relative strength of each these competencies, most services remain quite insular in their approach to developing technologies and, subsequently, rely on their own internal S&T Lab rather than look to the other services for premium technology development capabilities or leveraging opportunities *(Davis 2006)*. This chapter looks at the specific technical capabilities and proficiencies inherent with each of the S&T Labs. An analysis is performed to identify each lab's mission, objectives, organizational structure, technology focus areas, and past successes. The information from this analysis is then is used in Chapter IV to identify and integrate the S&T Lab best suited to mature critical technologies common to the SR, DD(X), and FCS programs.

B. DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

1. Laboratory Mission and Service History

Established in 1958, the Defense Advanced Research Projects Agency's (DARPA) primary mission is to nurture and develop advanced technologies and systems that create immense advantages to the U.S. military on the battlefield (DARPA, 2005). This push to develop immense technological advantages also has an additional motive: to minimize and prevent technological surprise from U.S. adversaries, while simultaneously creating such surprise for our enemies. In order to accomplish these goals, DARPA remains independent from the

military branches of the DoD. Program managers in DARPA usually engage in extremely risky, but high-payoff research and development efforts and are consistently encouraged to seek new technologies and methods for executing wars. Not satisfied to just simply “explore ideas”, these program managers strive to obtain results that can be implemented in a future military application. These research efforts, in essence, bridge the gap between basic scientific research and military application of science for strategic advantage. Figure 3.1 shows that the “*Service S&T*” (or S&T Labs) efforts are focused on near term technology development and the transition (application) of those technologies to a military system. “*Fundamental Research . . . Concept Invention*” is focused on the investigation of basic science and the determination of “what is possible” from a pure scientific standpoint *(DARPA, 2005)*. Although invaluable, this form of research is normally 10 to 20 years away from transitioning into a military application. As Figure 3.1 shows, DARPA has great expertise taking fundamental science that might have militaristic value, rapidly developing the science, and turning it into a technology for a potential military use.

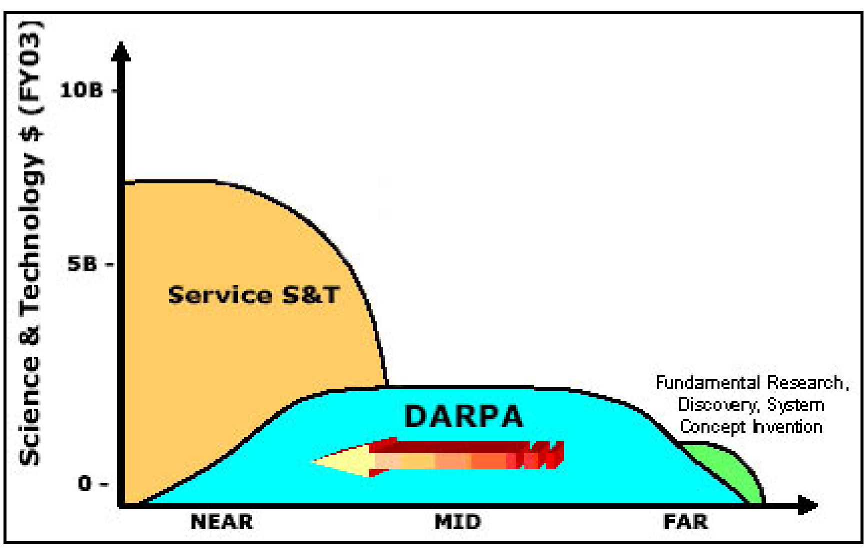

Figure 3.1: DARPA Program Implementation Horizon
(From: DARPA, 2005)

2. Organizational Structure

DARPA is divided into seven distinct research and technology directorates, with an additional directorate primarily focused on the design, development, and joint interoperability concerns of unmanned air vehicles. The seven primary directorates are organized to maximize synergism, by bringing together technology and focus area experts with similar interests. The themes of the directorates are set by the DARPA Director based upon his interactions with the current administration's cabinet and staff (i.e., Secretary and Under Secretaries of Defense, Chairman of the Joint Chiefs of Staff, Combatant Commanders, Service Secretaries, Service Chiefs, Service units, etc.).

DARPA is further divided into two basic divisions: technology and systems. The technology division focuses on new component technologies and basic sciences that might have significant national security application, while the systems division focuses on actual technology development programs that might lead to military end-item products. The technology division consists of Defense Sciences Office, Microsystems Technology Office, and Information Processing Technology Office. The systems offices are Tactical Technology Office, Special Projects Office, Advanced Technology Office, and Information Exploitation Office. Figure 3.2 depicts the DARPA.organization.

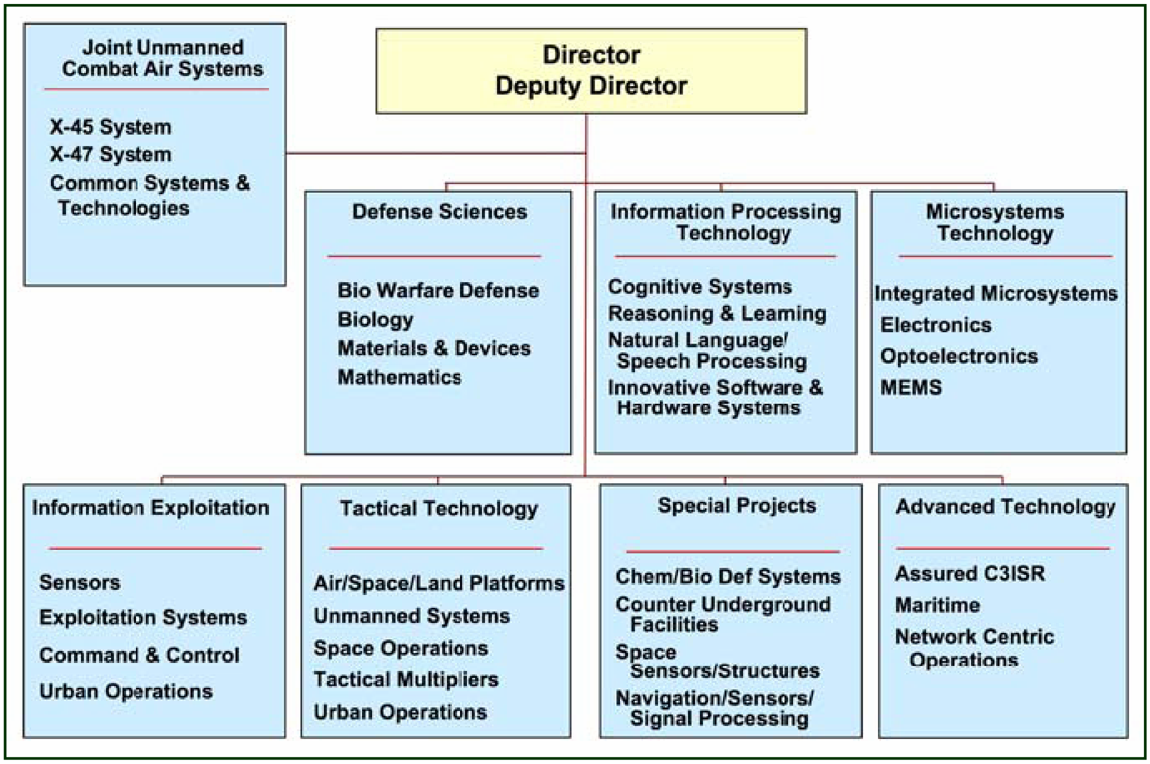

Figure 3.2: DARPA Organizational Structure
(From: DARPA, 2005)

3. Technology Development Focus Areas

As stated earlier, DARPA is strategically organized with separate technologies and systems development in order to maximize the potential for each division to identify and fully develop a revolutionary capability for the U.S. military. The mission and the technical focus for each of DARPA divisions are now described.

a. Defense Sciences Office

The Defense Sciences Office (DSO) of DARPA was established to research and tenaciously develop the most promising technologies for use across a broad spectrum of the U.S. science and engineering research communities and to turn those technologies into innovative, revolutionary capabilities for the military.

b. Information Processing Technology Office

The Information Processing Technology Office (IPO) focuses on DoD military superiority through development of novel networking, computing, and software technologies.

c. Microsystems Technology Office

The Microsystems Technology Office focuses on the integration of electronics, photonics, and microelectromechanical systems (MEMS). These high risk/high payoff technologies seek to protect the U.S. against biological, chemical, and information attack. This office also focuses on combined manned/unmanned warfare, adaptive military planning and execution processes, and operational dominance for mobile command and control units in a distributed environment.

d. Information Exploitation Office

Innovative sensor and information systems technologies are developed within the Information Exploitation Office (IEO). This office focuses on applying these technologies for battle space awareness, targeting, command and control and addresses critical challenges associated with performing surface target interdiction in environments that require very high combat identification confidence and low probability of collateral damage.

e. Tactical Technology Office

Similar to the DSO, the Tactical Technology Office (TTO) engages in high-risk, high-payoff advanced military research, while distinguishing itself by focusing on the “system" and "subsystem" methodology of systems development. This office focuses on air, space, sea, and land systems as well as embedded processors and control systems.

f. Special Projects Office

The Special Projects Office (STO) performs critical research and development activities necessary to demonstrate and transition technologies and systems that enable strategic military operations throughout the entire spectrum of conflict. The goal of this office is to demonstrate integrated prototypes of cost-effective assets the military can use to engage and defeat emerging threats.

g. Advanced Technology Office

The Advanced Technology Office (ATO) researches, demonstrates, and develops revolutionary technologies focused on communications, information assurance, special operations, and survivability mission areas. Supporting all aspects of military conflict, this office seeks to develop high-payoff, advanced technologies and adapt them to military systems for respond to global military requirements.

4. Technology Development Case Studies & Leverage Opportunities

The information below highlights recent programs developed and demonstrated by DARPA, provides examples of the technical proficiencies maintained throughout the organization, and serves to suggest opportunities for technology leveraging across the DoD.

a. Phased Array Radars

DARPA pioneered the construction of large, ground-based, phased array radars, such as the FPS-85, with a program called Electronically Steered Array Radar (ESAR). The FPS-85 phased array radar had a range of several thousand miles and could detect, track, identify, and catalog earth-orbiting objects and ballistic missiles. The FPS-85 quickly became part of the Air Force SPACETRACK system and is currently operational *(Perry, 1997)*.

DARPA's experience with the FPS-85 radar makes it an ideal organization to develop the ESA technology for Space Radar, as well as develop

the Dual-Band Radar for the DD(X) program. DARPA could also play a significant role in the development of FCS's MEMs Antenna, based upon the radar targeting and tracking algorithm development gained through the FPS-85 program.

b. Joint STARS

DARPA and the Air Force jointly developed an airborne target acquisition weapon delivery radar program, Pave Mover, under the DARPA Assault Breaker Program. The Pave Mover system was the demonstrator and became the basis for the Joint STARS airborne target detection and weapon assignment program that was as successful in Desert Storm as in real-time support to the commanders for both battle area situation assessment and targeting roles *(Perry, 1997)*. The experience gained through development of the Pave Mover's target acquisition and tracking system makes DARPA keenly suited to develop the FCS Signature Movement algorithms as well as the software and hardware required of the SR GMTI system.

c. Army Tactical Missile System (ATACMS)

The Army Tactical Missile System (ATACMS) is the centerpiece of the Army's precision strike modernization effort. It is a long-range, quick-response, surface-to-surface artillery rocket system with all-weather, day/night capability to be deployed against a wide range of targets, including critical mobile targets. It saw action during Desert Storm, where it was used to neutralize or destroy several surface-to-air missile sites, a logistics site, a refueling point, vehicles on a pontoon bridge, and other targets *(Perry, 1997)*.

With its capability for precision strike, quick-response, and all-weather capability, the ATACMS system should provide a sound technical baseline from which to develop the DD(X) Peripheral Vertical Launch System (PVLS). The experience gained through developing and integrating the ATACMS system makes DARPA an ideal laboratory to develop the PVLS system for the DD(X).

d. Cermet Materials for Armor

Variations of the Lanxide material discovered by M. Newkirk at Lanxide Corporation have been used successfully as armor for the Marine Corps' Light Armored Vehicles (LAV) in Operation Desert Storm (particularly for roof protection from artillery) *(Perry, 1997)*. Further development and insertion of this material into the Army inventory was funded by the DARPA ceramic insertion program *(Perry, 1997)*. Seventy-five LAVs and multiple transport aircraft, such as the C-17, were up-armored as a result of the early adoption of this material. DARPA's development of the Lanxide material increased its cost-effectiveness and makes both the material and DARPA's development capability worthy of integration into the FCS program *(Godfrey, 2005*)

e. Unmanned Undersea Vehicle (UUV)

There are a number of Navy missions in the littoral that cannot be performed safely by a full-sized, manned platform. They include mine location and avoidance as well as remote surveillance. In 1988 a joint DARPA/Navy Unmanned Undersea Vehicle (UUV) Program was initiated with the goal of demonstrating that UUVs could meet specific Navy mission requirements. The Navy initially pursued a submarine launched UUV that would either guide the submarine through an area that might be mined or search an area for mines. As a result of the end of the Cold War, the Navy revised the program with the objective of developing a tethered shallow water mine reconnaissance vehicle for littoral warfare. The system was demonstrated in the Joint Mine Countermeasures Advanced Concept Technology Demonstration (ACTD) in 1998 *(Perry, 1997)*.

The development of critical under-sea vehicle and mine-avoidance technologies make DARPA ideally suited laboratory to develop the DD(X)'s Integrated Undersea Warfare System.

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C. NAVAL RESEARCH LABORATORY

1. Laboratory Mission and Service History

In 1992, the Secretary of the Navy consolidated multiple Navy RDT&E and Fleet Support facilities to form a corporate community of scientific exploration and technology development entities aligned under one corporate research umbrella: the Naval Research Laboratory (NRL) *(DeYoung, 2005)*.

As the Navy's single integrated R&D entity, NRL provides the Navy with a broad foundation of in-house expertise from basic scientific research through advanced development activity. NRL has been specifically chartered to assumed leadership for the United States Navy in the following key areas *(NRL, 1999)*:

- Primary in-house research in the physical, engineering, space, and environmental sciences.
- Broadly based applied research and advanced technology development program in response to identified and anticipated Navy and Marine Corps needs.
- Broad multidisciplinary support to the Naval Warfare Centers.
- Space and space systems technology, development, and support. *(NRL, 1999)*

The NRL mission is to operate as the Navy's corporate laboratory. Responsible for creating and implementing a broad program of scientific research , NRL focuses on developing advanced technologies for new and improved components, techniques, systems, and oceanic and space sciences. In fulfillment of this mission *(NRL, 1999)*:

- Initiates and conducts broad scientific research in areas of interest to the Navy.

- Conducts exploratory and advanced technological development.
- Develops prototype systems applicable to specific projects.
- Assumes responsibility as the Navy's principal R&D activity in areas of unique professional competence.
- Performs scientific research and development for other Navy, DoD, & Government agencies.
- Serves as the lead Navy activity for space technology and space systems development and support.
- Serves as the lead Navy activity for mapping, charting, and geodesy (MC&G) research and development for the National Geospatial-Intelligence Agency (NGA).

2. Organizational Structure

Figure 3.3 depicts the organizational structure of the Naval Research Laboratory. A detailed description of the four technical offices (Material Science and Component Technology, Naval Center for Space Technology, Systems, Ocean and Atmospheric Science and Technology) is now provided.

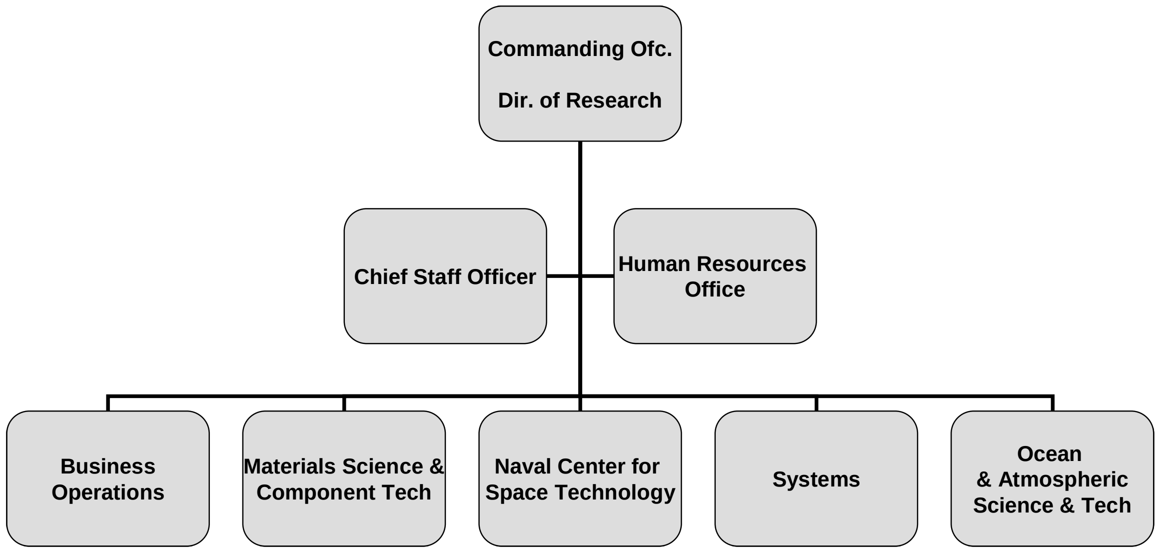

Figure 3.3: Naval Research Laboratory Organizational Structure (Circa. 2006)
(From: NRL, 2005)

3. Technology Development Focus Areas

The Naval Research Laboratory consists of four technology directorates. These organizations focus on technology areas deemed critical to strategic dominance of Naval tactical and strategic operations. A description of these directorates follows.

a. Systems Directorate

The Systems Directorate focuses on expanding operational capabilities and providing material support to Fleet and Marine Corps missions. These goals are accomplished through implementation of basic research through design and engineering development. The directorate emphasizes technology, devices, systems, and the knowledge to acquire and disseminate battle data; it also acts as the focal point for lab-wide development in signature technology, counter-signature technology, theater missile defense, and the Naval Science Assistance Program *(NRL, 1999)*.

b. Materials Science and Component Technology Directorate

The Materials Science and Component Technology Directorate carries out a broad, multidisciplinary development program to discover and exploit new materials, generate new systems concepts based on the behavior of these materials, and develop advanced components derived from these new materials and concepts. Researchers in this directorate perform detailed analysis to determine the scientific origins of materials behavior. They also develop methodologies for modifying these materials to meet naval requirements for advanced electronics, sensors, photonics, and platform technologies *(NRL, 1999)*

c. Ocean and Atmospheric Science and Technology Directorate

This directorate provides the Navy with critical research data in the fields of remote sensing, marine geosciences, acoustics, oceanography, space science, and marine meteorology. These data include remote sensing physics, imaging systems research, ocean dynamics and prediction, marine physics, seafloor sciences, ultraviolet space measurements, X-ray astronomy, upper atmospheric physics, and solar physics *(NRL, 1999)*.

d. Naval Center for Space Technology

The Naval Center for Space Technology was added to NRL in an effort to enhance a strong naval space technology base and to provide expert assistance for naval missions impacted by the design, development, and acquisition of specific, data-intensive space systems. (See Figure 3.4) This center acts as the focal point and consolidator for all NRL offices whose technologies are deployed or exploited through space systems

4. Technology Development Case Studies & Leverage Opportunities

The information immediately below highlights recent programs developed and demonstrated by NRL. These programs provide examples of the technical proficiencies maintained throughout the organization and further serve to suggest opportunities for technology leveraging across the DoD.

a. Low Observables Detection Radar

NRL developed and tested an advanced development model shipboard radar that detects and tracks sea-skimming missiles near the horizon in difficult littoral environments, with low false alarm rates. The radar operates simultaneously in both surface and air modes, with the air mode providing an unprecedented clutter rejection level that is orders of magnitude better than previous technology such as the Empar or Sampson surface radar systems *(DeYoung, 2005)*. The surface mode is able to track small boats and helicopters in heavy sea clutter. The technology was light weight and obtained at low cost.. The radar, now named the AN/SPQ-9B Anti-Ship Missile Defense radar, was transitioned to Northrop Grumman for production *(DeYoung, 2005).* NRL's technology and radar development expertise has potential application for both the DD(X) Dual-Band Radar and the SR Electronically Scanned Array technologies.

b. Low Solar Absorbance (LSA) Paint

NRL developed Low Solar Absorbance (LSA) paint in order to reduce solar heating on Navy ships. Tested in 1995, the paint produced a significant reduction in surface temperatures during summertime operations in the Gulf of Mexico. Testing demonstrated that the LSA paint not only reduced ship surface temperatures and the load on air conditioning systems, but it also decreased the ship's infrared (IR) signature, reducing the susceptibility of all coated Navy ships to hostile IR sensors and IR-guided munitions. The per-gallon cost of the LSA paint is identical to the Standard Haze Grey paint it replaces,

resulting in a cost-effective infrared stealth technology for the Navy. It is now the standard paint applied to all U.S. Navy vessels *(DeYoung, 2005).* The design, testing, and integration processes used to develop the LSA paint technology can also be employed in the DD(X) program to meet the stringent Hull Form and Infrared Mockup technology requirements.

c. Software Defined Radios

In 1994, the U.S. Army contracted NRL to develop an airborne Tactical Operational Center (TOC) that was formerly housed in a UH-60 Army Blackhawk helicopter. To meet the Army's need to support 37 heritage radios, NRL developed the Joint Combat Information Terminal (JCIT), an eight-channel software radio designed to meet the environmental, volume, and power constraints of the UH-60. The JCIT, through the utilization of software, took the place of the 37 heritage radios, demanding only a fraction of the latter's size, power, and weight.

The JCIT program was the first program to demonstrate that software-definable radios could be the basis for solving tactical communications problems. Many of the processes and implementation mechanisms developed for the JCIT have been adopted by the Joint Tactical Radio System (JTRS). JTRS is mandated as the basis for acquisition of all future tactical communication systems *(DeYoung, 2005)*.

With its technology used as a basis for all future tactical communication systems, NRL demonstrates that it is uniquely qualified to develop software defined radio technology for the FCS, as well as to broaden its software communications algorithms for the DD(X)'s Total Ship Computing Environment requirement.

D. ARMY RESEARCH LABORATORY

1. Laboratory Mission and Service History

The Army Research Laboratory (ARL) is the Army's corporate basic and applied research laboratory. With a mission to provide innovative science and technology development for combat operations, ARL is focused on key science and technology building blocks that will enable the transformation of the Army into a more versatile, agile, survivable, lethal, deployable, and sustainable force.

In 1945, the Army issued a public policy, affirming the need for civilian and commercial-sector scientific contributions in weapons production and military planning. In 1946, a new Research and Development Division (RDD) of the War Department General Staff was established. This new organization was quickly closed, however, due to internal politics that favored the traditional technical service structure. Over the course of the next four decades, the Army's science and research capability was restructured several times. In 1989, the presiding commander of the current research and development structure recommended an integration of all the laboratories under one physical entity. As part of the Base Realignment and Closure Act of 1989, the Federal Advisory Commission reviewed this recommendation and accepted the creation of ARL in 1992.

The current ARL structure consists of an administrative branch, the Army Research Office (ARO), and six technical development Directorates – Weapons and Materials, Sensors and Electron Devices, Human Research and Engineering, Computational and Information Sciences, Vehicle Technology, and Survivability and Lethality Analysis (Miller, 2003). These directorates provide the U.S. Army with key scientific discoveries, technological advances, and analyses to provide warfighters with capabilities to quickly and confidently engage and defeat enemies on the battlefield.

2. Organizational Structure

Figure 3.4 depicts the organizational structure of the Army Research Laboratory. A detailed description of the six technical directorates is now provided.

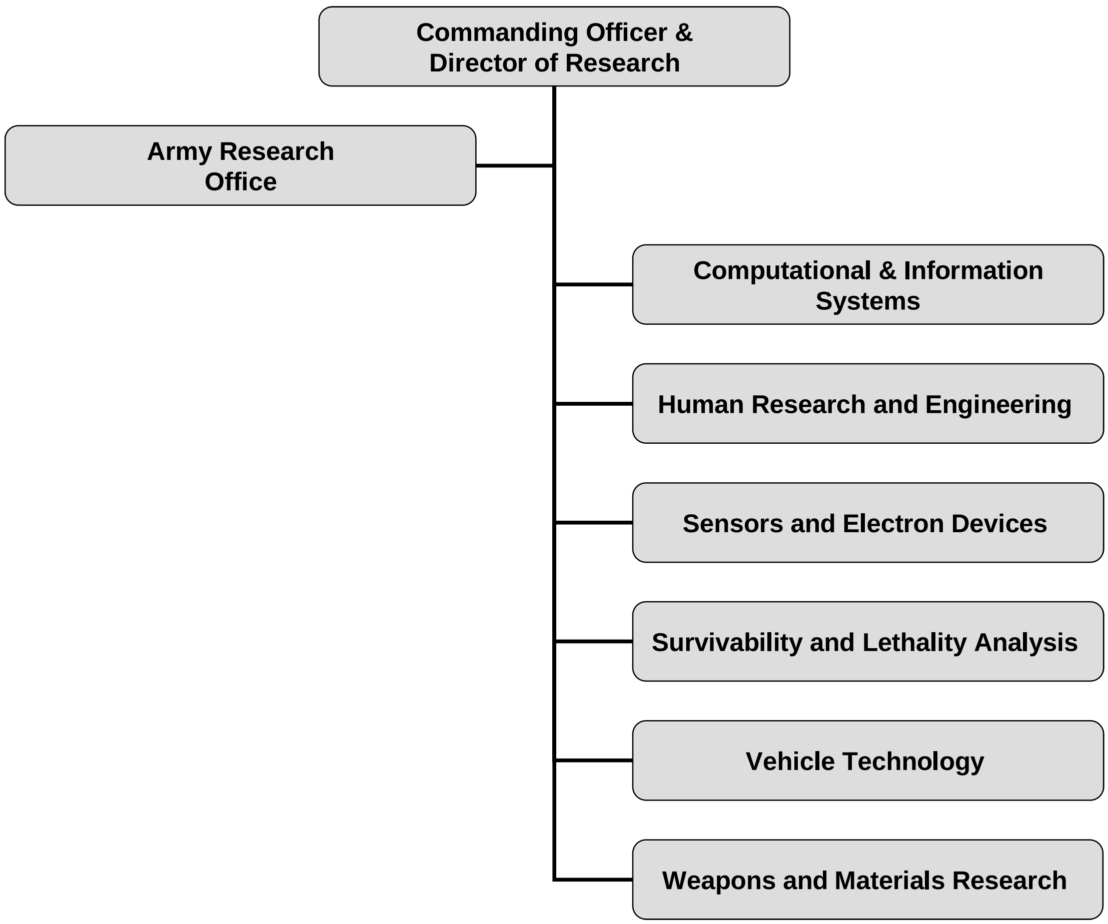

Figure 3.4: ARL Organizational Structure (Circa 2006)
(From: Miller, 2003)

3. Technology Development Proficiencies

As stated earlier, ARL primarily consists of six technology directorates. These organizations focus on technology areas deemed critical to strategic dominance of Army tactical and strategic operations. A discussion of these directorates follows.

a. Computational and Information Sciences Directorate

This directorate is responsible for conducting a broad, multidisciplinary research effort focused on high bandwidth communications, advanced techniques for combat command and control, battlefield visualization, weather decision aids, and defensive information operations.

b. Human Research and Engineering Directorate

This organization performs scientific research and seeks to develop technology directed toward optimizing the performance of individual soldiers and their interactions with mechanisms and equipment for maximizing battlefield effectiveness. This directorate ensures that soldier performance requirements are adequately considered in technology development and system design.

c. Sensors and Electron Devices Directorate

This strategic Sensors and Electron Devices directorate develops advanced solid-state components and state-of-the-art sensor systems.

d. Survivability and Lethality Analysis Directorate

Responsible for integrating survivability and lethality analysis of Army systems and technologies into tools for battlespace characterization, the Survivability and Lethality Analysis directorate looks across a broad variety of battlefield threats and environments to assess and project future battle performance.

e. Vehicle Technology Directorate

This directorate addresses structural engineering and propulsion technologies for both ground and air vehicles in partnership with the National Aeronautics and Space Agency (NASA).

f. *Weapons and Materials Research Directorate*

As a critical contributor to the Army's ability to project force and win wars, the Weapons and Materials Research directorate is responsible for material and weapons research to develop the technologies for future land combat systems.

4. Technology Development Case Studies & Leverage Opportunities

The information immediately below highlights recent programs developed and demonstrated by ARL. These programs provide examples of the technical proficiencies maintained throughout the laboratory and serve to suggest opportunities for technology leveraging across the DoD.

a. *Lightweight Machine Gun and Ammunition*

The ARL's Lightweight Machine Gun and Ammunition program will result in mature technologies that would enable the weight reduction of weapons and ammunition used by the Future Warrior. ARL will investigate the feasibility of employing polymeric materials as a replacement for the existing brass cartridge case material with the goal of reducing the case weight by 40%. ARL specifically focuses on the identification of structurally robust polymers capable of withstanding the thermal and mechanical environment experienced in a gun chamber, the development of appropriate boundary conditions and nonlinear material property databases for evaluation of candidate polymer materials, and the characterization of candidate polymer materials (ARL, 2001). The reduction of the size and weight of field weapons and artillery could potentially provide significant benefits to the development of the DD(X)'s Advanced Gun System. The identification of structurally robust polymers with nonlinear material properties could also play a large role in satisfying the FCS requirement for Low Cost Composites.

b. Advanced Propulsion and Transmission Fundamentals

This basic technology program is aimed at developing a fundamental understanding of new, advanced aerodynamic engine component concepts, advanced mechanical component concepts to enable major advances in rotorcraft mechanical power transmission, and high temperature materials and structures to enable substantial increases in efficiency, power density, and affordability of small gas turbine engines (ARL, 2001). The experience gained in this program will provide ARL with an understanding and competency of aerodynamic engine and power concepts. This competency can be applied to the FCS's Advanced Power Storage and Silicon Carbide Switch technologies and leveraged in the development of the necessary subsystems and components for the DD(X)'s Integrated Power System.

c. Power Components for Hybrid Electric Vehicles and Pulse Power

This program will provide compact, high density power component technologies for Future and Current Force Hybrid Electric Vehicle Propulsion, Pulse Power (survivability/lethality), and related applications. Tasks in this effort include the investigation and maturation of technologies to provide high-temperature, high-frequency power converters and generators; high-power batteries operating over a large temperature range; high-temperature, high energy density fast/medium current rise time storage capacitors; and Micro-Electronic Mechanical Systems (MEMS) for improved efficiency and reliability (miniature portable generators, miniature engines, and fuel cells) (ARL, 2001).

ARL's investment in pulse power and hybrid-electric vehicles will yield significant dividends to the development of FCS's Advanced Energy Storage and Silicon Carbide Switch technologies. The development of high-power batteries that operate over a large temperature range will directly support SR's Lithium Ion requirement as well as provide the DD(X) with energy storage and power sourcing technology for its Integrated Power System.

E. AIR FORCE RESEARCH LABORATORY

1. Laboratory Mission and Service History

The Air Force Research Lab's (AFRL) mission is to lead discovery, development, and integration of affordable, warfighting technologies for our air and space forces. Focused on responding to customer needs and continuously improving the processes that enable Science and Technology (S&T) advancements, AFRL develops revolutionary technologies to transform military operations. Its goal is to improve capability, create new capability, or reduce ownership costs by an order of magnitude. To that extent, AFRL emphasizes affordability through consideration of commercial-off-the-shelf technology solutions at each stage of technology development. Additionally, the laboratory seeks to take maximum advantage of computational techniques to lower the cost of research, development, testing and other activities that help discover, develop, transition, and qualify systems for operational use.

2. Organizational Structure

Figure 3.5 depicts the organizational structure for the Air Force Research Laboratory. A detailed description of the nine technical offices (Air Vehicle, Directed Energy, Human Effectiveness, Information, Materials and Manufacturing, Munitions, Propulsion, Sensors, Space Vehicles) is further provided below.

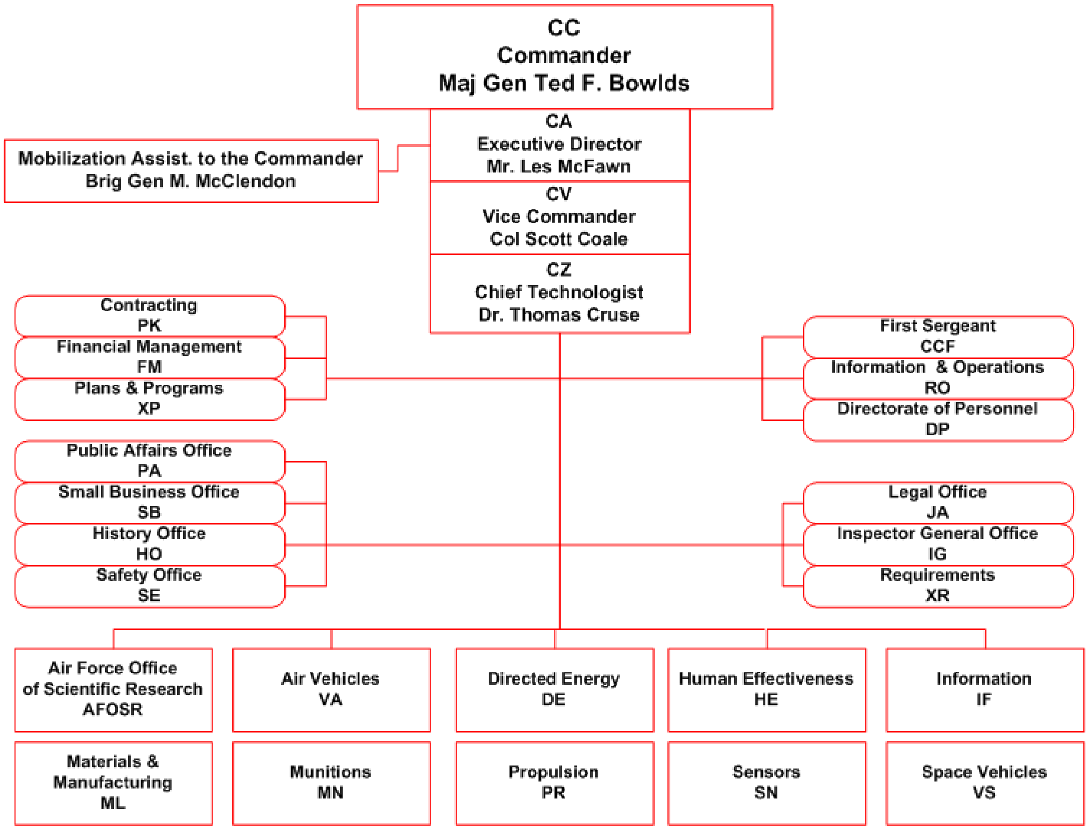

Figure 3.5: Air Force Research Laboratory Organizational Structure
(From: AFRL, 2003)

3. Technology Development Proficiencies

AFRL consists of nine strategically architected technology directorates. These organizations focus on developing the basic science, technologies, and components necessary to ensure the Air Force's dominance in air and space for the next generation of warfare. A description of these directorates and their individual technology focus areas follows.

a. Air Vehicles Directorate

The AFRL Air Vehicles (VA) directorate is primarily responsible for developing and transitioning advanced technology solutions that enable dominant, survivable, and cost-effective military aerospace vehicles. These vehicles must be capable of quick and accurate delivery of a multitude of future

weapons or cargo anywhere in the world. To achieve this goal, AFRL/VA focuses on developing aeronautical sciences, control sciences, structures and integration, and ultimately targets advanced concepts that will provide future capabilities in the areas of sustainment, unmanned air vehicles, space access, and future strike.

b. Directed Energy Directorate

The Directed Energy directorate engages in research and development for leading-edge space capabilities through the development, integration and transition of technology for directed energy applications to include: high power microwaves, lasers, adaptive optics, imaging and effects. The directorate improves and transitions optical systems to war-fighting commands to ensure air and space dominance in association with direct energy applications.

c. Human Effectiveness Directorate

The Human Effectiveness directorate develops, integrates, and transitions technologies for training personnel. With a focus on improving the interface between the warrior and the weapon system, this organization develops technologies to protect and sustain Air Force warfighters to assure the preeminence of U.S. aerospace forces. The directorate has eight core technology areas: warfighter skill development and training, training simulation, information display and decision support, crew system design technologies, directed energy bioeffects, toxic hazards effects, crew protection, and logistician effectiveness *(AFRL, 2003)*.

d. Information Directorate

The Information Directorate develops information technologies for military air, space, and ground systems. This organization focuses on technologies associated with information fusion and exploitation, communications

and networking, collaborative environments, modeling and simulation, defensive information warfare and intelligent information systems technologies *(AFRL, 2003)*.

e. Materials and Manufacturing Directorate

A critical AFRL component, the Materials and Manufacturing directorate develops new materials, processes and manufacturing technologies for use in aerospace applications such as aircraft, spacecraft, missiles, rockets, and ground-based systems and their structural, electronic and optical components. Utilizing a vast network of advanced materials and analysis laboratories, this organization also provides quick reaction support and real-time solutions to Air Force system acquisition offices and maintenance depots to solve materials related concerns and issues. This directorate is also responsible for developing and executing advanced manufacturing technology programs and affordability initiatives, addressing manufacturing process technologies and integrating manufacturing excellence into the design of current and future Air Force systems *(AFRL, 2003)*.

f. Munitions Directorate

The Munitions directorate is responsible for developing, demonstrating, and transitioning air-launched munitions technology for defeating ground fixed, mobile, air and space targets to assure dominance of U.S. air and space forces *(AFRL, 2003)*.

g. Propulsion Directorate

The Propulsion directorate is the Air Force focal point for developing air and space vehicle propulsion and power technologies. This organization focuses on developing innovative and radical technology in the areas of turbine and rocket engines, advanced propulsion systems, and the associated fuels and propellants for all propulsion systems *(AFRL, 2003)*.

h. Sensors Directorate

The Sensors directorate develops technologies required by Warfighters in finding and precisely engaging the enemy, and, additionally, eliminating the enemy's ability to hide or threaten U.S. forces. This directorate develops sensors for air and space reconnaissance, surveillance, precision engagement and electronic warfare systems, with the goal to provide a full range of air and space sensors, a complete and timely picture of the battlespace, and precision targeting of the enemy. The core technology development areas for this organization include radar, active and passive electro-optical targeting systems, navigation aids, automatic target recognition, sensor fusion, threat warning and threat countermeasures.

i. Space Vehicles Directorate

The Space Vehicles directorate develops and transitions space technologies to increase the effectiveness and affordability of warfighter space missions. This organization focuses on the following research areas to ensure pre-eminence in space technology development: radiation hardened electronics; space power; space structures and control; space based sensing; space environmental effects; autonomous maneuvering; and balloon and satellite flight experiments *(AFRL, 2003)*.

4. Technology Development Case Studies & Leverage Opportunities

The information immediately below highlights some programs recently developed and demonstrated by AFRL. These programs provide examples of the technical proficiencies maintained throughout the organization and further serve to suggest opportunities for technology leveraging across the DoD.

a. Advanced Ultra-Triple-Junction Solar Cells

AFRL, in coordination with Spectrolab Inc, has developed extremely advanced ultra-triple-junction (UTJ) solar cells. These cells were

chosen to power the solar arrays aboard two National Aeronautics and Space Administration (NASA) Mars rovers. As highly efficient collectors of the sun's photo-voltaic energy, single-crystal multijunction (MJ) solar cells maximize solar panel electrical output. When compared to the single MJ solar cell, the UTJ solar arrays provide a 50% improvement in cell efficiency over the cells used on the earlier Mars Pathfinder mission. The UTJ cells utilize a three-layered structure to more effectively capture and convert solar energy into electricity. Each of the junction cells converts a different portion of the solar spectrum into electricity, vastly improving energy conversion efficiency *(SOLAR, 2006)*. AFRL's experience in developing advanced solar cells for NASA and other Air Force satellite missions makes it uniquely qualified to develop this technology for the SR program.

b. High-Strength Armor Plating

AFRL materials scientists worked with Excera Materials Group to develop an innovative metal-ceramic hybrid material for use in high-performance, lightweight, low-cost small arms protective inserts (SAPI) for body armor vests. This material, called ONNEX, provides the high hardness of boron carbide, but it also provides fracture toughness ten times that of the leading pressed ceramic material, Hafnium Diboride. The hardness of an ONNEX armor plate will shatter and stop a striking bullet, and because the material's fracture toughness confines damage to a small area, the armor can tolerate multiple strikes to the same region. During a 6-month deployment to Iraq, the 88th Security Forces Squadron field-tested the armor to evaluate its strengths and weaknesses. Upon their return, squadron members provided feedback, including recommendations related to fit and "wearability." In just 18 months, this low-cost, high-payoff technology development program evolved from initial laboratory research and development work into a technology system that exceeds the capabilities of most current SAPI plates. The technology manufacturing process requires lower temperatures and shorter processing times, leading to substantial cost savings *(ARMOR, 2006)*

AFRL-developed ONNEX has proven invaluable to the 88th Security Forces deployed to Iraq. The material's light weight and hardness could potentially be key to meeting the requirements of FCS's Low-Cost Composite technology; and the material's light weight and hardness may play a prominent role in the development of DD(X)'s Hull Form technology.

c. Low-Cost Expendable Unmanned Air Vehicle

The COUNTER project involves a small unmanned air vehicle (UAV) called the BAT-3, which flies at altitudes of 2,000 to 10,000 feet while collecting video telemetry that enables potential targets to be nominated for further inspection *(COUNTER, 2006)*. The BAT-3 works in conjunction with a micro UAV (the Nighthawk). The Nighthawk flies at still lower altitudes in the urban area, performing close-range surveillance of nominated targets to determine if a threat exists. The two UAVs send their collected video telemetry to the Vigilant Spirit Control Station, the command and control interface, for analysis.

During recent tests conducted at the Jefferson Proving Grounds, located in southern Indiana, researchers conducted a series of three UAV flights over two days to test BAT-3 and Nighthawk performance. Although weather limited some of the tests, the researchers successfully confirmed the connectivity, two-way communication, video telemetry transmission, and cooperative control algorithms of both the two UAVs and the Vigilant Spirit Control Station. The tests also verified each UAV's ability to autonomously generate and follow specified trajectories. Future COUNTER project tests will include flight demonstrations in an urban terrain environment, which will test the vehicles' navigation capabilities in cityscapes *(COUNTER, 2006)*.

With MEM technology playing a critical part in the development of the Bat-3 UAV, AFRL has demonstrated a competency for developing micro electro-mechanical systems. This demonstrated competency could be leveraged in the development of FCS's MEM Antenna technology.

IV. ALLOCATING CRITICAL TECHNOLOGIES ACCORDING S&T LABORATORY CAPABILITIES

A. INTRODUCTION

This chapter identifies opportunities for leveraging technology development across the services. With the critical technologies identified in Chapter II for the SR, DD(X), and FCS programs, an analysis is performed to determine the common technologies amongst the three programs. As a result of this analysis, a composite matrix identifies common subsystem requirements, which ultimately lead to common technology requirements. The analysis indicates that Lithium Ion Batteries and Electronically Scanned Arrays are the common technology requirements shared by all three systems (SR, DD(X), and FCS) and represent opportunities for technology development leveraging.

This chapter also identifies the S&T Lab best suited to develop these common, critical technologies. With the laboratory focus area information from Chapter III, another composite matrix is created to capture a comparison of the demonstrated development experience of each S&T Lab with the development requirements for Lithium Ion Batteries and ESA technology. The comparison show that the Army Research Lab has the development expertise and demonstrates manufacturing experience necessary to develop the Lithium Ion Battery technology for all three DoD programs, while the Naval Research Lab has the design, integration, and application experience necessary to develop the Electronically Scanned Array technology for the SR, DD(X), and FCS programs.

B. SCIENCE & RESEARCH AREAS FOR THE DEPARTMENT OF DEFENSE

In Chapter I of this thesis, technology is identified as “the cornerstone of every fielded acquisition program in the Department of Defense,” and further defined as a necessary component for DoD programs to “develop a complete system that can meet functional, technical, and operational requirements.” With

technology representing such an important facet of the military's success, and with the inherent challenges of efficiently developing, transitioning, and deploying technologies, it is imperative that the various generalized areas in which technology plays a key role in the systems acquired by the DoD be understood. Moreover, the identification of real technology development leveraging opportunities and the ultimate establishment of an inter-service leveraging capability requires that a framework for categorizing the various types of technology-driven acquisition systems be created. This categorization will consequently allow for the comparison of technology needs across the three DoD acquisition programs assessed in this thesis and the appropriate allocation of S&T Labs to perform the necessary technology development and transition.

As Figure 4.1 shows, the first step in this process of identifying technology leveraging opportunities is to define the technology areas that comprise the major portions of current and future DoD acquisition systems.

The technologies shown in Figure 4.1 represent the main science areas of interest to the DoD and directly coincide with the various focus areas identified by each of the S&T labs discussed in Chapter III. In the next section, these scientific focus areas are compared to the development needs across the three DoD acquisition programs. This comparison will aid in the allocation of technology development responsibilities to the S&T Lab best suited to help each program accomplish its mission goals.

<u>Science & Technology Research Areas for DoD</u>

- Power Generation
- Power Storage
- Munitions
- Air Propulsion
- Space Propulsion
- Chemistry
- Materials
- Software
- Computer Systems
- Networking Systems
- Surveillance Technology
- Radar
- Remote Sensing
- Optics
- Electronics
- Bimolecular Science
- Physics
- Oceanography & Marine Science
- Space Science & Phenomenology

Figure 4.1: Department of Defense S&T Laboratory Focus Areas

C. ANALYSIS OF COMMON TECHNOLOGY REQUIREMENTS

Systems developers and acquisition officials have known for years that there is a great degree of commonality amongst the various systems in development across the DoD, but political and funding issues, scheduling doubts, and questions regarding the technical prowess of each of the S&T Labs have created an air of resistance to leveraging the development efforts of the S&T Labs *(Davis, 2006)*. In this section the requirements of the three DoD programs are dissected and merged to reveal the inherent leveraging potential.

Depicting the critical technologies for the three next-generation DoD programs categorized by their military science applicability, Figure 4.2 provides a corollary and grouping of technologies by science, rather than by service orientation or planned use.

		Science & Technology Research Areas for The Department of Defense															
		Power Generation	Power Storage	Munitions	Ari Propulsion	Space Propulsion	Chemistry	Materials	Software	Computer Systems	Network Systems	Surveillance Technology	Radar Systems	Remote Sensing	Optics	Electronics	BioMolecular Science
AIR FORCE Technology Requirements	Electronically Scanned Array (ESA)											X	X	X		X	
	On-board Processor								X	X	X					X	
	Information Management System								X	X	X					X	
	Ground Moving Target Indication (GMTI) HW & SW								X	X	X	X					
	Advanced Solar Cells	X						X									
	Lithium Ion Batteries		X				X										
NAVY Technology Requirements	Advanced Gun System			X													
	Autonomic Fire Suppression System						X		X	X							
	Dual Band Radar								X	X		X	X			X	
	Hull Form							X									
	Infrared Mockup							X									
	Integrated Deckhouse and Apertures							X									
	Integrated Power System	X	X						X	X						X	
	Integrated Undersea Warfare System								X	X						X	
	Peripheral Vertical Launch System			X	X												
	Total Ship Computing Environment								X	X	X						
ARMY Technology Requirements	MEMS Antenna (ESA Technology)									X		X	X	X		X	
	Advanced Power Storage Technologies		X				X										
	Software Defined Radios								X	X						X	
	Silicon Carbide Switches		X					X								X	
	Low Cost Composites						X	X									

Figure 4.2: Science & Technology Application Matrix

As the matrix in Figure 4.2 shows, several opportunities exist for development leveraging across the services. Additionally, many of the critical technologies required from by the three DoD programs are built upon identical fundamental sciences. Figure 4.2 also shows that there are groups of common technology applications that can be drawn through particular military applicable science categories. Specifically, each group represents a pool of critical technologies that require a similar type of research and development work to be performed in any specific scientific category. These groups are shown in Figure 4.3.

		Power Generation	Power Storage	Munitions	Ari Propulsion	Space Propulsion	Chemistry	Materials	Software	Computer Systems	Network Systems	Surveillance Technology	Radar Systems	Remote Sensing	Optics	Electronics	BioMolecular Science
		Science & Technology Research Areas for The Department of Defense															
AIR FORCE Technology Requirements	Electronically Scanned Array (ESA)											X	X	X		X	
	On-board Processor								X	X	X					X	
	Information Management System								X	X	X					X	
	Ground Moving Target Indication (GMTI) HW & SW								X	X	X	X					
	Advanced Solar Cells	X						X									
	Lithium Ion Batteries		X				X										
NAVY Technology Requirements	Advanced Gun System			X													
	Autonomic Fire Suppression System						X		X	X							
	Dual Band Radar								X	X		X	X			X	
	Hull Form							X									
	Infrared Mockup							X									
	Integrated Deckhouse and Apertures							X									
	Integrated Power System	X	X						X	X						X	
	Integrated Undersea Warfare System								X	X						X	
	Peripheral Vertical Launch System			X	X												
	Total Ship Computing Environment								X	X	X						
ARMY Technology Requirements	MEMS Antenna (ESA Technology)									X		X	X	X		X	
	Advanced Power Storage Technologies		X				X										
	Software Defined Radios								X	X						X	
	Silicon Carbide Switches		X					X								X	
	Low Cost Composites						X	X									
			1					2		3						4	

Figure 4.3: Science & Technology Application Matrix: Commonality Groups Identified

Groups 1-4 shown in Figure 4.3 represent the pools of technology that would benefit the most from a leveraged technology development initiative. Although it would appear that the other groups, such as network systems and software, share a similar level of commonality, the potential to leverage those technologies is decreased given their highly specialized and application specific nature of network hardware and software.

The commonality groups (reflected by the colored triangles) are analyzed to determine the specific, fundamental technology requirement that is shared amongst the programs within each group. A detailed discussion of each group follows.

1. Group 1: Power Storage

This group is comprised of the power capture and storage technologies across the three services. As shown in Figure 4.4, the Power Storage group is broken-out into the individual technologies required by the services, and the underlying science or components that comprise the technology.

	Program	Critical Technology	Fundamental Requirements
GROUP 1 Power Storage	**Space Radar**	Lithium Ion Batteries	**Lithium Ion Technology**
	DD(X)	Integrated Power System	Electric Flywheels, Super Capacitors, **Advanced Batteries**, Advanced Electrical Disribution, High Energy Weapons
	Future Combat System	Advanced Power Storage Technologies	Super Capacitors, **Lithium Ion Technology**

Figure 4.4: Commonality Group 1: Power Storage

As Figure 4.4 shows, several underlying components across the varying programs contribute to the power storage technology. High-powered capacitors, innovative flywheels, and classical cell batteries form the baseline of the technologies that have potential applicability to the three DoD programs. Figure 4.4 also shows that Lithium Ion batteries represent a common thread in this power storage group (in bold red text). With its broad application across DoD, and even in commercial sectors, a leveraged development program to mature Lithium Ion technology would yield a large return on investment across the services and should be investigated further

2. Group 2: Materials

This group is comprised of the physical building block technologies for most of the structures, metals, carbon fiber, and other substrates employed by the DoD in various applications. As Figure 4.5 shows, these building-block substrates range from gallium-arsenide solar cell substrates to infra-red absorbing metals to light-weight composites.

	Program	Critical Technology	Fundamental Requirements
GROUP 2 Materials	**Space Radar**	Advanced Solar Cells	**Gallium Arsenide, Silicon Substrates,**
	DD(X)	Hull Form Infrared Mockup Integrated Deckhouse & Aperatures	Infra-Red Absorbant Materials, Maleable Carbon Fibers, Non-Reflective Paints, Corrosion Resitance Coatings, Carbon Fasteners
	Future Combat System	Low Cost Composites	Kevlar Alternatives, Vehicle Armor Plating, Ceramic Vest Inserts, Body Armor

Figure 4.5: Commonality Group 2: Materials

Figure 4.5 highlights the fact that the technologies and components comprised within the materials group are very disparate. Although the components and the technologies are deemed critical to their respective programs, they do not appear to be aligned to an extent great enough to warrant a leveraging opportunity that would be of benefit to the ST, DD(X), and FCS programs.

3. Group 3: Computer Systems

As indicated in Figure 4.3, the technologies in the Computer Systems group are pervasive in application. Each of the acquisition systems under review for this thesis utilizes one or multiple computer systems to implement its required functions and capabilities. Interestingly, each critical technology that employs a computer system to ensure functionality has a prominent, parallel software component to its overall design. History has shown that although hardware between various computer systems can be shared (hard drives, processors, memory), the software controlling the computers and the processing algorithms can be different *(Gates, 2005)*. It would therefore be ill-advised to attempt to create a common development structure for the hardware (and software) computer system that controls, for example, the SR GMTI technology and to leverage that with the FCS Software Defined Radios. These systems are so different in software implementation that any type of software leveraging across hardware platforms would likely result in a non-optimal set of software code for

one or both of the systems. This use of non-optimal software could potentially lead to erratic system operation and mission failure for these critical DoD systems.

4. Group 4: Electronics

Like the Computer Systems group, the Electronics group is a pervasive group with wide application across the three DoD services. Information Management Systems, Integrated Power Systems, and Micro Electro-Mechanical Antenna technology all rely on multiple electronic systems and subsystems to ensure proper functionality and capability. Figure 4.6 reflects these and other technologies that comprise this group of commonality.

	Program	Critical Technology	Fundamental Requirements
GROUP 4 Electronics	Space Radar	Electronically Scanned Array On-Board Processor Information Management System	**TR Modules**, Rad-Hard CPU, Database Software Algorithms
	DD(X)	Dual-Band Radar Integrated Power System Integrated Undersea Warfare System	**TR Modules**, Advanced Electrical Distribution, Advanced Sonar Sensing Technology
	Future Combat System	Mems Antenna (ESA Technology) Software Defined Radios Silicon Carbide Switches	**TR Modules**, Advanced Communications Software, High-Perf Silicon Carbide Sources

Figure 4.6: Commonality Group 4: Electronics

Among a multiplicity of electronic subsystems (Figure 4.6) that are shared across the DoD, the Electronically Scanned Array appears to be the most common. Not only is this electronic system (and its subsystems) shared by the three DoD programs, but it also represents a mission-enabling technology for both the SR and the FCS program. Consequently, this electronic system should be considered as a potential opportunity for technology development leveraging.

The commonality groups reveal at least two opportunities for technology leveraging across the three DoD programs. The first opportunity is in Group 1: Power Storage. This group will be further analyzed in the next section to identify an S&T Lab to perform the general development of the Lithium Ion technology,

and to assume responsibility for transitioning the battery technology to the individual service organizations for productization and qualification in their respective programs. The second opportunity is in the Electronics group. This group covers many technologies but, as shown by Figure 4.3, the Electronically Scanned Array shares the most commonality across all the three services. This group will also be assessed in the next section to identify a DoD S&T Laboratory to develop the ESA technology and transitioning it to the other services for integration.

The next section provides more detail on the utility of the two technologies across the three service programs, identifies an S&T Lab for development of each of the technologies, and provides a timeframe for transitioning the technologies to the services in accordance with their individual technology freeze dates.

D. LEVERAGING LITHIUM ION TECHNOLOGY DEVELOPMENT

In Section 2 of this chapter, Lithium Ion batteries are identified as one of the common technologies requiring transition into each of the three next-generation DoD acquisition programs. As assessed in Chapter II, Lithium Ion batteries are highly desirable power storage devices due in large part to their elevated power density. This particular characteristic yields output power that is several factors greater than its competing technology, Nickel Hydrogen (NH2) *(Gold Peak, 2000)*. When integrated into a system or application, this Lithium Ion technology offers the choice of a gain in output power while holding the weight constant, or a reduction in weight while holding the power output constant. The Space Radar system is envisioned to use this technology to conduct nighttime operations when the Sun does not shine on the solar cells to provide power. These batteries will allow the SR system to meet its 24-hour, continuous tracking and targeting requirement while providing weight and launch cost savings. The DD(X) program plans to integrate Lithium Ion battery technology into its Integrated Power System. Within this system, the batteries will be used to

augment the power distribution system and will thus provide increased flexibility in power use and allow the future integration of high energy, pulse, and laser weapons. Interestingly enough, the DD(X) program does not openly consider the integration of these batteries as a critical development milestone *(Lamartin, 2004)*. Instead the DD(X) program leaders have identified the development of the closely integrated propulsion motors as a significant technical challenge. The use of a leveraged methodology to develop Lithium Ion technology will allow the DD(X) design team to focus its efforts and resources solely on the propulsion motor and potentially allow another laboratory to perform the time-intensive Lithium Ion development work. The FCS is envisioned to utilize Lithium Ion technology to power the multiple land and air vehicles that will comprise the new Future Force *(Feikert, 2005)*. Faced with a requirement to travel great distances while continually tracking and performing power-intensive data transmit and receive operations, the FCS development team has identified this technology as a key enabler to meeting the requirement. The batteries' ability to store large amounts of energy, comparable light-weight, and extremely rapid recharge characteristics comprise the fundamental building blocks of the FCS capability.

With a specific, common need identified among the three programs, identification of an appropriate S&T Lab to perform the basic technology development is necessary. To determine which of the laboratories would be best suited for developing the Lithium Ion batteries, a set of criteria is developed. Rather than focus on specific knowledge of materials and chemicals associated with Lithium Ion formulation, these criteria are related to the demonstrated experience in developing batteries for high-energy applications and battery manufacturing processes such as prototyping, chemical formulation, system & subsystem testing, vehicle & weapon integration, etc. Figure 4.7 shows the criteria and their application to each of the S&T Labs. Although not exhaustive, these criteria are representative of the critical factors needed to determine the ability of an S&T Lab to perform a particular design, development, and transition mission *(Dobbins, 2004)*.

	Selection Criteria	S&T Laboratory			
		ARL	AFRL	NRL	DARPA
Lithium Ion Battery Development	Demonstrated Competency with Technology	✸		✸	✸
	Direct Program Development Experience	✸			✸
	Direct Manufacturing Experience	✸	✸		✸
	Vehicle / System Integration Experience	✸	✸	✸	
	Current Program Requirement	✸	✸	✸	
	Need Technology in Nearterm (12-18 months)	✸			
	Adequate Staffing for Productization Effort	✸			
	Applicability to Parallel Programs	✸	✸		
	Current Leveraging with Industrial Base	✸	✸	✸	

Figure 4.7: Lithium Ion Battery Development: S&T Lab Selection

As shown in Figure 4.7, the Army Research Lab is the organization best poised to develop the Lithium Ion batteries and to transition them to the three next-generation programs for final qualification and integration.

The Army Research Lab has been advancing the state-of-the-art in battery technology since the mid-1960's *(Miller, 2003)*. Its liquid electrolyte reserve and thermal battery technologies have been heavily utilized in multiple variants since the Vietnam war *(ARL, 2001)*. ARL has had experience developing both large, sealed lead-acid batteries for cannons, missiles, and anti-tank weapons, and small, lithium-based batteries for handheld weapons and communications equipment. It has also been involved in assessing and understanding the U.S. Industrial Base for batteries. Recognizing the dwindling market power that the DoD wields for custom battery technologies, the ARL has formed strategic alliances with three primary U.S. battery developers — Alliant Techsystems, EaglePitcher Technologies, and KDI Precision Products. These partnerships are intended to maintain critical battery development expertise within the U.S., while simultaneously providing ARL with a fast-track capability to develop and test new and advanced battery chemistries. Additionally, ARL has developed an internal battery group focused on creating and promoting new battery development opportunities through the ARMY Manufacturing Technology (Mantech) program

(ARL, 2001). ARL's experience in developing and integrating high-power batteries, coupled with their U.S. industrial base alliances and Mantech program, make it suited to produce the fundamental technology required by the Space Radar, Navy DD(X), and FCS systems.

E. LEVERAGING ELECTRONICALLY SCANNED ARRAY DEVELOPMENT

Electronically Scanned Arrays (ESA) represent another technology that could be leveraged and transitioned to each of the three next generation DoD acquisition programs. As discussed in Chapter II, an ESA is a revolutionary type of radar whose hardware functions are composed of numerous small transmit/receive (T/R) modules. Combining these T/R modules into a grid-like structure provides short to instantaneous (millisecond) scanning rates and an immobile, less mechanically complex system than conventional radar designs. For the Space Radar system, this technology represents the core of its functionality and the sole enabler of its capability. The ESA technology provides the SR system with a capability to track and engage a large number of targets simultaneously, without the need for mechanical slewing; the SR system will thus satisfy a requirement to continuously identify, target, and track land, air, and sea-based targets. Finally, ESA technology for SR immobilizes the radar and reduces the number of hardware components, resulting in the reduction of both the on-orbit weight of the satellite and the total satellite power requirement.

The assessment of the critical technologies in Chapter II shows similarities between the requirements for the ESA and Dual-Band Radar technologies. Both of these technologies will be used to continuously monitor airborne and surface activities, scan for low-flying threats, and provide information on missiles, aircraft, boats, or other threats. Figure 4.6 also shows similarities in the required subsystems that will provide these capabilities for the SR and DD(X) programs.

This information indicates that if the ESA technology is developed in a leveraged

fashion, components of this technology could be of use in meeting the DD(X)'s Dual-Band Radar requirement.

Similarly, the FCS acquisition can leverage the ESA technology development effort. The Army's Future Force is required to transmit and receive data over large distances and continually track multiple objects in different directions. Faced with these requirements, the FCS program intends to integrate the ESA technology into many of the manned and unmanned vehicle platforms in order to scan or broadcast communication signals over a broad range without physically moving an antenna *(Weiss, 2002)*.

With a specific, common need identified among the three programs, identification of an appropriate S&T Lab to perform the basic technology development is necessary. To determine which of the labs would be best suited for developing the Electronically Scanned Array technology, a set of criteria is developed. Deviating from the process used to determine the appropriate S&T Lab for Lithium Ion development, the methodology for choosing an optimum ESA development lab depends upon the application commonality of the technology as opposed to pure experience level. In other words, it would likely be advantageous for a ground-based ESA technology to first be developed, then shared between ground users (Army & Navy), and finally ported and transitioned to the Air Force for space application. A new, criteria-based assessment of the S&T Labs is performed with AFRL relegated to "observer" status. The criteria are based upon past experience and competency in developing radar-like technologies. Figure 4.8 shows the criteria matrix and provides a perspective on a possible S&T Lab to develop the ESA technology.

	Selection Criteria	S&T Laboratory: ARL	AFRL	NRL	DARPA
Electronically Scanned Array Development	Demonstrated Competency with Technology			✱	✱
	Direct Program Development Experience			✱	✱
	Direct Manufacturing Experience		✱	✱	✱
	Vehicle / System Integration Experience	✱	✱	✱	✱
	Current Program Requirement	✱	✱	✱	
	Need Technology in Nearterm (12-18 months)	✱			
	Adequate Staffing for Productization Effort	✱		✱	
	Applicability to Parallel Programs	✱	✱	✱	
	Current Leveraging with Industrial Base			✱	

Figure 4.8: Electronically Scanned Array Development: S&T Lab Selection

Figure 4.8 shows that the Naval Research Lab is best suited to develop the Electronically Scanned Array technology for integration into the three next-generation programs. It was the Naval Research Lab which, in 1922, invented modern day radar. NRL is also credited for developing the first airborne radar, land-based radar, and sub-marine radar system *(DeYoung, 2005)*. The laboratory has subsequently continued to develop radar technology, creating everything from phased array radars for atmospheric and meteorological research to innovative sonar and laser tracking systems for precise identification and targeting of threats on the littoral seas. Although radar technologies have always been important for Naval vessels, the post-Cold War threat environment has ushered in a desire to promote radar systems as key enablers for mission success using a reduced fleet with ships that are smaller and more agile than the current fleet of Naval vessels *(NRL, 2005)*. In light of this new dynamic, NRL has developed a comprehensive radar development capability in its Surveillance Technology Branch, which is responsible for basic and applied research, advanced technology demonstrations, and test and evaluation of new, innovative naval radar systems. Consistent with the development requirements of the

Electronically Scanned Array system, this NRL branch focuses heavily on the development of new radar concepts, advanced radars, and new signal-processing/detection techniques. The advanced capabilities for radar development at NRL will enable the laboratory to develop an ESA technology capability for the DD(X)'s use on the littoral seas and for implementation in a land-based setting for the FCS program. This development capability will also provide a significant risk reducer and baseline technology for the Space Radar as the program transitions this technology from the Naval Research Lab to the SR satellite acquisition.

F. INTEGRATION & TRANSITION SCHEDULE

Chapter II provides insight into the Technology Freeze Date (TFD) for each of the programs assessed in this thesis. Each of the technologies outlined within the commonality groups (Lithium Ion Batteries and Electronically Scanned Arrays) must be developed and matured prior to each program's TFD. The development of these technologies must also follow each program's individual acquisition milestones. These milestones represent significant waypoints for the maturation of acquisition systems and provide senior DoD leadership with insight into the relative stability and meaningful progress of these programs. Sections A and B in Chapter 5 discuss the development schedules for the SR, DD(X), and FCS programs. A review of these schedules provides insight into the technology integration and transition requirements of the three DoD programs.

1. Integration Schedule for Lithium Ion & ESA Technology: Air Force Space Radar

As Figure 4.9 shows, the Space Radar program goes through its Critical Design Review (CDR) in the 4th quarter of FY2010. This design review is the final assessment of a system's design and technology maturity before Pentagon officials give the program the green light for full production. The TFD represents the date at which all technology development and system design must stop in preparation for the CDR. Therefore, in order to ensure the utility of the Lithium-

Ion and ESA technology, these technologies must be inserted far prior to the TFD, with enough time afforded for complete transition. Figure 4.8 shows that this insertion should optimally occur between the first and third quarter of FY2008 *(Payton, 2003)*. Based upon the DoD's directive for systems acquisition, this insertion timeframe would provide 24 – 30 months during which the program office can concurrently perform the necessary productization and qualification activities necessary to make the Lithium Ion batteries qualified for space, and to ensure that the Electronically Scanned Arrays have the reliability, radiation-hardening, and performance necessary to continuously target and track objects on the Earth's surface.

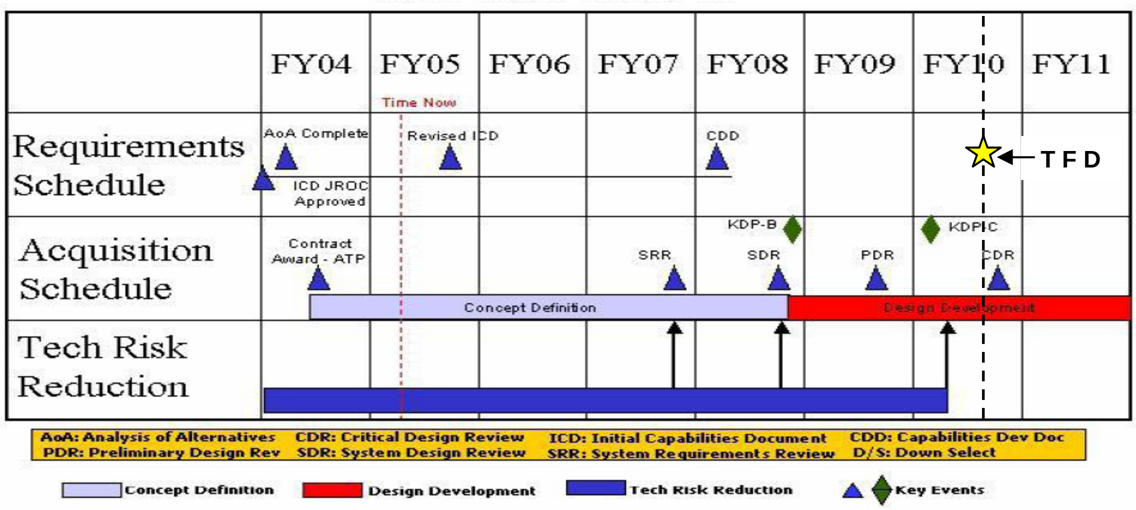

Figure 4.9: Leveraged Technology Insertion Schedule: Space Radar
(From: Department of the Air Force, 2006)

2. Integration Schedule for Lithium Ion & ESA Technology: Navy DD(X)

As discussed in Chapter II, the Navy DD(X) program and naval senior leadership hold a unique perspective with regard to the U.S.Navy's system acquisition schedules and the need to define technology freeze dates. In response to a scathing GAO report regarding the DD(X)'s planned schedule for

technology maturation and integration, USN Captain Glenn F. Lamartin states " . . . The DD(X) schedule and the execution of the EDMs in time for ship installation, which for shipbuilding programs, is the most relevant point of reference for technology maturity, provided a perspective on the schedule for technology maturing for naval programs." *(Lamartin, 2004)* This would indicate that the final date acceptable for technology insertion would be the 2nd quarter of FY11, coincident with the first DD(X) ship delivery. However, this viewpoint is in stark contrast to previously documented technology insertion successes, such as the Acoustic Rapid COTS Insertion (A-RCI) and Common Submarine Radio Room, and it is not consistent with the guidance provided in the Defense Acquisition Handbook *(Payton, 2003)*.

In order to comply with DoD guidance and to follow the example of other successful insertion efforts, the technologies should be inserted into the program between the 4th quarter of FY2008 and the 1st quarter of FY2009 (Figure 4.10). This would provide the program with 24 – 30 months to perform the necessary integration and follow-on productization activities required to make Lithium Ion and ESA technology part of the DD(X)'s first delivery.

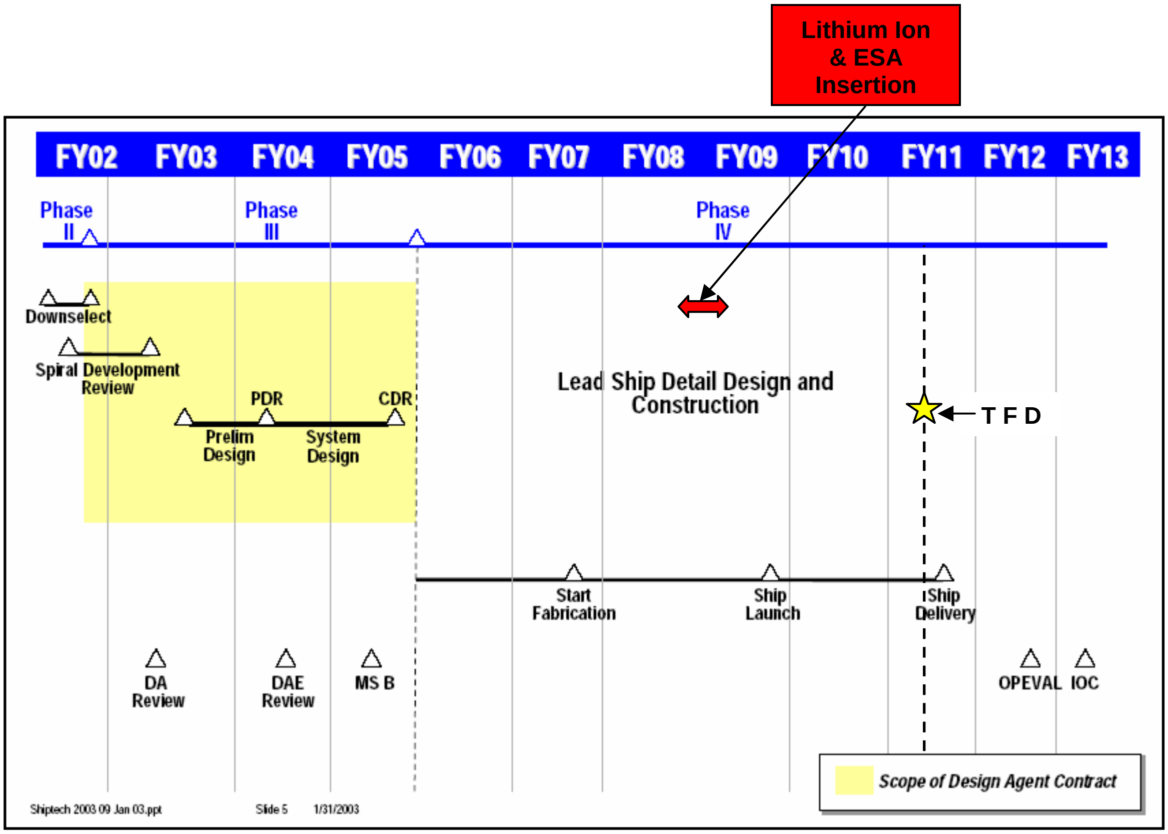

Figure 4.10: Leveraged Technology Insertion Schedule: Navy DD(X)
(From: Peoships, 2003)

3. Integration Schedule for Lithium Ion & ESA Technology: Army Future Combat Systems

After announcing plans to accelerate the delivery of the selected FCS components to FY2008, Army FCS officials quickly realized that the technologies necessary to make the system a reality would not be ready for several years after this time period. They adopted a plan to "Spin-Out" (SO) select technologies. Under this plan, the FCS deliveries would occur every two years and gradually add technology and capability with each delivery through FY2013 . This plan provides a unique opportunity for the FCS development team. By integrating the technology between the 1st and 2nd quarters of FY2009 (Figure 4.11), the FCS development team would have 36 months to integrate, develop, test, and qualify the Lithium Ion & ESA technologies into the various FCS vehicle platforms. The

FCS Spin-Out methodology thus provides a risk reduction capability on top of the leveraging already experienced through the synergistic technology development with the Navy and the Air Force.

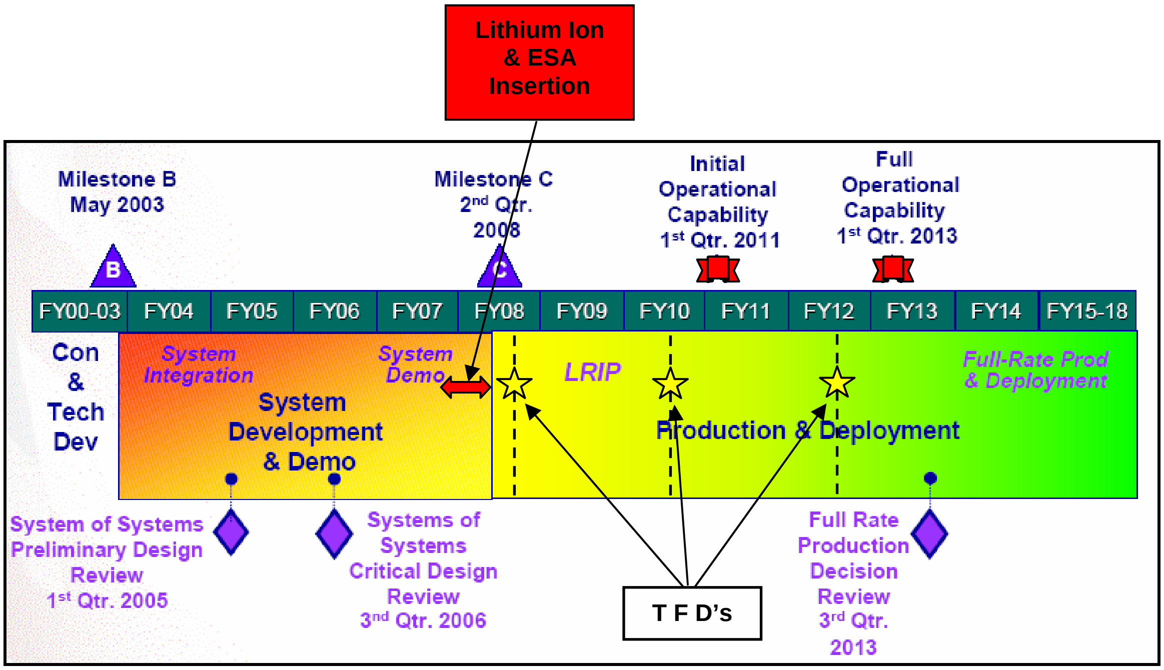

Figure 4.11: Leveraged Technology Insertion Schedule: Future Combat Systems

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V. CONCLUSION AND RECOMMENDATIONS

A. INTRODUCTION

This final chapter summarizes the opportunities for technology leveraging across the SR, DD(X), and FCS programs, their common technologies, and the S&T labs most qualified for developing and integrating these technologies for all three programs. It also summarizes the applications of leveraged technology development across the DoD and the potential limitations of this methodology. Finally, recommendations for future study of technology leveraging architectures are provided.

B. PRINCIPAL RESULTS

According to the findings of this research, first of all, through careful planning and coordinated technology transition, DoD acquisition programs can indeed leverage the technology development efforts of the three services within the DoD. In particular, the Air Force's Space Radar program, the Navy's DD(X) program, and the Army's Future Combat Soldier program all identify Lithium Ion Batteries and Electronically Scanned Arrays as technologies critical to the success of their missions. The results of this study show that the DoD is not required to engage in three similar and parallel development activities to mature and integrate each of these technologies. The Army Research Lab and the Naval Research Lab both have the capability and integration experience to develop the technologies and transition them to all three of the services. In particular, ARL has demonstrated the ability to rapidly develop, mature, and transition technology to support the Technology Freeze Dates for systems similar in size and scope to the SR, DD(X), and FCS systems.

Second, having demonstrated competence in manufacturing complex battery and energy storage solutions and a long history of partnering with the U.S. battery industrial base, ARL should develop Lithium Ion technology and integrate it for all three systems.

Finally, having designed and developed multiple ESA technology variants for previous systems and, consequently, direct manufacturing and integration experience with this technology, the Naval Research Lab should develop the Electronically Scanned Array technology for the three DoD systems.

The leveraging opportunities identified in this study will enable significant cost savings and schedule efficiency to the SR, DD(X), and FCS programs. The time and resources that would have been used to independently develop Lithium Ion and ESA technologies by each of the services can be allocated to the development of other technologies or subsystems of the systems Moreover, this technology leveraging strategy will expedite the transition and integration of the identified technologies into the programs, helping to ensure the deployment of these extremely critical defense programs.

Although this research focuses on the three DoD acquisition systems, the identification of technology development leveraging opportunities can be applied on any system developed for military use. Furthermore, industry technology development programs and their commercial development laboratories can be included in this leveraging process. The technologies needed for industrial/commercial programs should be compared with DoD technology requirements to identify commonality. Additionally, the development competencies of commercial laboratories should be assessed and compared to those of the DoD S&T Labs in order to identify the best allocation of resources for DoD or Industry technology development programs.

There are limits, however, to the application of this leveraging strategy. In this work, the leveraging strategy is assumed to result in the services experiencing some relief from individually funding Lithium Ion and ESA

technology development. With such funding relief, the services would be forced to project a reduced level of spending in their yearly program schedule and undoubtedly receive a decreased level of funding in the remaining years of the program development. This funding reduction alone would be a sufficient reason for the services to limit or possibly to avoid any type of cooperative agreement.

Moreover, in some scenarios, simultaneous development of identical technology is not only necessary, but advantageous. Multiple services developing common technology can provide a significant reduction in development risk as well as create an incremental development capability. Multiple concurrent developments may also be necessary to maintain the military's operations tempo, or even sustain a key industrial base partner to a particular service or S&T Lab.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

As follow-on to this research, a detailed programmatic plan should be created for Lithium Ion technology, developed with active participation from Army FCS, Air Force SR, and Navy DD(X) representatives. This programmatic plan will use real-time cost, schedule, and other parameters to effectively create a tangible, leveraged development capability for the DoD. With participation from all three services, this plan would be elevated to the senior DoD leadership level (Undersecretary) for advocacy and buy-in. The results reported in this thesis should form the basis of this programmatic plan.

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